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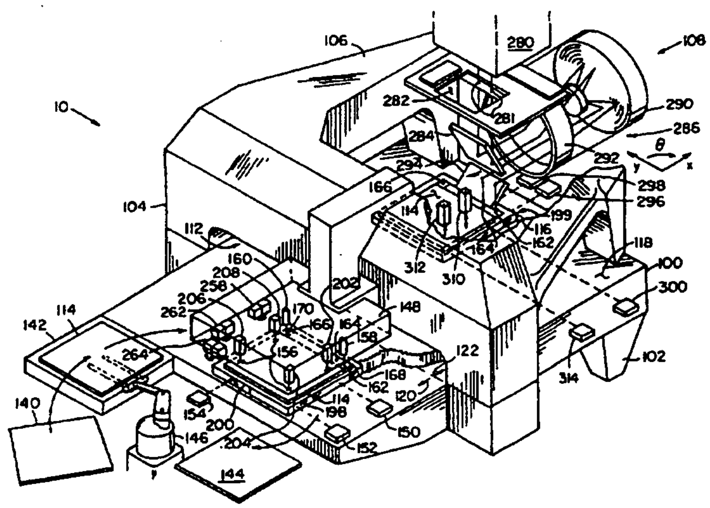

(57) Abstract

A remote alignment system for a lithography tool is disclosed in which a position of the substrate relative to the stage is first determined. Then, when the stage is moved to the projection system, only the stage needs to be aligned to the projection system. Two stages (116) are used so that one stage can be at the alignment station (120) while another stage is at the projection station (122). Thus, alignment and exposure can happen simultaneously for different substrates increasing production speed. Further, a fine alignment system is described that simultaneously detects the location of several alignment marks on the substrate. Each of the alignment mark detectors (202, 204, 206, 208) projects a relatively simple image onto the substrate's alignment marks (156) which are scanned under the detectors thus allowing the system to obtain more information about the substrate without increasing the time to capture this information.

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LITHOGRAPHY SYSTEM WITH REMOTE MULTISENSOR ALIGNMENT

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RELATED APPLICATIONS

This application is a Continuation-in-Part of U.S. Application Serial Nos. 08/692,290, filed August 2, 1996 entitled "Lithography System with Remote Multisensor Alignment", 08/693,469, filed August 2, 1996, entitled "Non Contact Edge Detector", and 08/733,810, filed October 18, 1996, entitled "Lithography System with Remote Multisensor Alignment", the contents of which are incorporated herein in their entity.

BACKGROUND OF THE INVENTION

Lithography systems are used to project patterns onto a photo-sensitive material on a substrate. In the manufacture of integrated circuits, the photo-sensitive material is termed a photoresist, and the substrates are usually wafers in the case of semiconductor chip production or glass sheets, or similar transparent material, in the case of flat panel display production.

After the photoresist has been exposed, the substrate is removed from the lithography system, and the photoresist is developed. The developing process strips away the photoresist according to the projected pattern to selectively lay bare the substrate. This allows the selective processing of the substrate's surface. A new material layer may be deposited; or the exposed substrate may be chemically reacted, such as through oxidation or

etching. These processes can involve baking and annealing the substrate along with physical manipulation such as spinning or cleaning, which can physically distort the substrate to varying degrees. Later, the remaining photoresist is stripped away.

The integrated circuits are completed only after several exposure-development-processing cycles, each involving the projection of different patterns onto successive photoresist layers by the lithography system. This procedure leads to the requirement that each successive projected pattern during the separate production cycles must be aligned with respect to the previously projected patterns on the substrate. This is termed overlay alignment and can be complicated by the fact that the processing may have distorted the substrates.

Overlay alignment, however, is not the only criticality. Exposure during each production cycle involves the separate projection of many images to form the desired pattern. The portion of the substrate's surface that is processed is typically large relative to the surface area covered by a single projected image from the projection system. The projection of many images in a grid pattern is required to cover the substrate.

When many separate chips are being formed on a wafer, as in the case of DRAM or microprocessor manufacture, each projected image is the size of a single chip. Therefore, a given projected image need only be aligned to the previous projected images for the individual chip currently being exposed.

When flat panel displays are being manufactured, however, only a few display devices are manufactured on each glass sheet substrate. Each display is large relative to the projected image. Thus, each projected image must

additionally be aligned to adjacent projections to properly form the desire projected pattern across the entire substrate. This requirement results from the fact that essentially a single integrated circuit is being formed across the surface of the glass sheet for each display. The process of aligning or abutting projected images is termed stitching alignment.

Overlay and stitching alignment are achieved through the use of alignment marks that are formed on the substrate during a previous exposure-development-processing cycle. The projection system of the photolithography system is then later aligned relative to the alignment marks. Then the substrate is precisely moved underneath the projection system using interferometers to achieve overlay and stitching alignment with respect to successive projected images within a cycle.

The alignment marks may also be used to detect the distortions in the substrate caused by the handling and processing of the substrate during each production cycle. The location of the alignment marks relative to each other is determined and compared to previous production cycles to detect the nature and magnitude of any changes. The location of each projected image may then be finely tuned to optimize both overlay and stitching alignment. This process is most important in the context of flat panel display manufacture where the glass sheets are prone to distortion and the location of each projected image affects every other projected image to some degree. The process, however, is also relevant to chip manufacture on wafers when only a few alignment marks are used to align the projection system for a much larger number of separate chips.

Lithography alignment systems that use the alignment marks fall into two general categories: through-the-lens

systems and off-axis systems. Through-the-lens systems are the simplest insofar as the systems provide for direct alignment of the projection system to the substrate. Commonly, a mark on the projection system's reticle is compared to the substrate's alignment mark. The substrate is then positioned so that a predetermined relationship is achieved between the two marks.

Off-axis alignment systems rely on a separate system that is dedicated to measuring the location of alignment marks. The typical type of off-axis system images the alignment mark pattern onto a detector such as a charge-coupled device (CCD), which has a fixed and known relationship with the projection system. Once the detector locates the mark, the substrate can be moved a known distance to properly locate it under the projection system.

The costs associated with the use of the lithography system to expose the substrate during each of the separate production cycles represents one of the most significant cost factors in the manufacture of a chip or display device. The detection of the separate alignment marks followed by the actual projection of the separate images of each exposure cycle requires a non-trivial length of time. Therefore, it is important to speed the operation of the system.

SUMMARY OF THE INVENTION

In the typical lithography system, alignment occurs at or near the projection system, and thus must occur serially in time with exposure. This inefficiently uses the machine since the expensive projection system is idle during alignment, and the alignment system is idle during exposure.

The present invention is based upon the recognition that alignment can be accomplished remotely from the projection system. This ability distinguishes it from through-the-lens systems that use the projection system to align the substrate and also from off-axis systems where the alignment system is near and in a fixed, known relationship with the projection system.

In the present invention, alignment and exposure can happen simultaneously, albeit for different substrates. That is, one substrate can be aligned at an alignment station while another substrate is being exposed under the projection system. Thus, the speed of production is no longer limited by the total time to align plus the time to expose. The time required by the lithography system to produce a single substrate in the context of mass production is reduced by the shorter of the alignment time or the exposure time.

In general, according to one aspect, the invention concerns a remote alignment system for a lithography tool. The system comprises at least one stage which transports substrates between an alignment station and projection station. Preferably, however, two stages are used so that one stage can be at the alignment station while another stage is at the projection station.

The alignment station functions to determine the position of the substrate relative to the stage. Once this is determined, the stage is transported to the projection station where only the stage needs to be aligned relative to the projection system. At that point, the projection system can be used to successively expose portions of the substrate.

In specific embodiments, the stages move over a planar platen on air bearings. Linear motors in each stage electromagnetically interact with the platen to provide propulsion along both x- and y-axes. The stages also have platen-stage position detecting systems that coarsely determine a position of the stage by reference to the platen. According to the remote alignment technique, the stages may move between the alignment station and the projection station only in response to these platen-stage detection systems which are relatively inaccurate in comparison to interferometer systems that are typically used in off-axis and through-the-lens alignment systems to control the stage's movement between alignment and projection.

According to other specifics of the embodiments, the alignment station comprises a stage position detection system that is used to determine a location of the stage in a coordinate system of the alignment station. The stage position detection system comprises a stage homing system that is used to home the stage relative to the alignment station's coordinate system. The homing system can be constructed from transmissive alignment sensors (TAS). Displacement detectors, or interferometers, are then used to measure the movements of the stage within that coordinate system.

According to still other specifics of the embodiments, the substrate is located within the alignment station's coordinate system by a substrate alignment system. This system comprises at least one alignment mark detector that includes a projector, which forms an image on the substrate alignment marks, and a detector, which detects light diffracted by the alignment marks. Preferably, four or more of these detectors are used to simultaneously detect

the location of corresponding alignment marks. This allows the simultaneous reference to multiple alignment marks to speed the alignment process.

According to still further specifics of the embodiments, the projection station also comprises a stage position detection system that determines a location of the stage in the coordinate system of the projection station. Preferably, this comprises at least one transmission alignment detector on which the projection system forms a pattern. In this way, the stage is quickly homed with respect to the projection system. Thereafter, the stage is moved under control of displacement detectors, *i.e.*, interferometers. Since the relationship between the stage and the substrate is known, the substrate can then be properly located underneath the projection system during exposure.

According to another aspect, the invention also features a method for aligning and exposing a substrate on a stage of a lithography tool. This method includes first determining the position of the substrate relative the stage at an alignment station. Then, the substrate is transported to a projection station where the stage is aligned relative to the projection system. The projection system is then used to successively expose the substrate.

According to still another aspect, the invention also features a substrate alignment system that simultaneously detects the location of several alignment marks on the substrate. This is accomplished with multiple alignment mark detectors that are connected to a sensor platform and positioned such that they are each located above a corresponding alignment mark on the substrate. Each of the

alignment mark detectors projects a relatively simple image onto the substrate's alignment marks. As a result, all of the alignment marks can be simultaneously scanned under the corresponding alignment mark detector. This allows the alignment system to simultaneously detect the location of multiple alignment marks. This feature distinguishes it from systems that use only a single alignment mark detector, but then successively move different ones of the alignment marks on the substrate underneath the detector. As a result, the time to align the substrate in the present invention can be as short as the time to detect only a single alignment mark on the substrate.

In general, according to still a further aspect, the invention features a pre-alignment system for a lithography system. The pre-alignment system is comprised of multiple substrate edge detectors, each of which comprises a projector, preferably located above the substrate, that projects a light field down onto a substrate and a stage. The light field has a predetermined shadow line. In the preferred embodiment, this shadow line is straight and runs perpendicularly to the direction of the substrate's edge. A camera of each edge detector is also located above the substrate and detects the light from the light field. The height differential between the substrate and stage causes a shift in the shadow line from the perspective of the camera. A controller connected to the camera utilizes this shift to locate the edge of the substrate.

In specific embodiments, the projector comprises a light stopped source of light and projection optics that form an image of an edge of the light stop onto the substrate and stage to form the shadow line. An optical axis of the projector may lie in a plane that is perpendicular to the substrate and stage and contains the

edge of the substrate. It is preferred that the optical axis is shifted slightly out of the plane away from the substrate. This hides a halo or penumbra on the stage, which is caused by the substrate's edge, from the camera's view. The optical axis of the camera preferably lies substantially in the plane. The projector and camera axes are angled from the vertical and intersect near to the substrate edge such that projected light reflected at the edge is received by the camera. The angle of inclination of the projector, however, is different than the angle of inclination of the camera, so that the camera does not receive specularly reflected light from the substrate's top surface which could saturate a detector.

In other specifics of the embodiments, the controller receives information from each camera and identifies the shift in the corresponding shadow lines by summing pixels along a direction that is orthogonal to the shadow line incrementally over at least a portion of the shadow line's length. The changes in intensity are indicative of the edge's location.

The above and other features of the invention including various novel details of construction and combinations of parts, and other advantages, will now be more particularly described with reference to the accompanying drawings and pointed out in the claims. It will be understood that the particular method and device embodying the invention are shown by way of illustration and not as a limitation of the invention. The principles and features of this invention may be employed in various and numerous embodiments without departing from the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale; emphasis has instead been placed upon illustrating the principles of the invention. Of the drawings:

Fig. 1 is a perspective schematic view, with a partial cut-away, of the lithography system of the present invention;

Fig. 2 is a top plan view showing a stage on the platen of the lithography system;

Fig. 3 shows the quad-cell layout and reticle for the TAS detector and a vertical cross section of a TAS projector;

Fig. 4A is a schematic cross-sectional view of the dark-field detector of the present invention;

Fig. 4B shows details of a reticle and projected image of the dark-field detector;

Fig. 5A is a plan view of an alignment mark that is compatible with the inventive dark-field detectors;

Fig. 5B shows another embodiment of the alignment mark according to the present invention;

Fig. 6 is a voltage verses time plot of the response of a photodetector of the dark-field detector as an alignment mark on substrate is scanned underneath it;

Fig. 7A is a schematic perspective view of a non-contact substrate edge detector of the present invention;

Fig. 7B is a schematic perspective view showing the construction of the projector and the light field with the shadow line;

Fig. 7C is a plan view showing the field of view of the camera relative to the light field;

Figs. 7D, 7E, and 7F are a top plan, side, and detailed top views showing the angular relationship of the projector and camera relative to the substrate and stage;

Figs 7G, 7H, 7I are top, side, and camera perspective views of the light field and shadow line created on the substrate and stage;

Figs. 7J and 7K are a side and camera perspective view of the light field for a transparent substrate;

Fig. 7L is a vertical cross-sectional view of a beveled edge of a substrate located on the stage;

Fig. 7M shows the shadow line and the light field from the camera's perspective for a transparent substrate with a beveled edge;

Fig. 8 is a block diagram showing the control system of the invention;

Figs. 9A and 9B are a flow diagram showing a process for manufacturing substrates according to the present invention;

Figs. 10A, 10B, and 10C are top plan views showing the placement of the alignment marks relative to the dark-field detectors in three embodiments of the invention; and

Figs. 11A and 11B illustrate the technique for repositioning sensors on the sensor platform.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows a lithography system 10 which has been constructed according to the principles of the present invention.

A base 100 is preferably a granite slab that provides a massive and rigid foundation for the system 10. Mechanical isolation systems 102 connect the base 100 to the floor to provide immunity from the transmission of environmental vibration into the system 10.

A granite bridge 104 (shown in partial cutaway) sits upon the base 100 and vaults upwardly over the base arching between the two sides of the base. From a top perspective,

the bridge is horseshoe-shaped with the ends 106 of the horseshoe supported at the back of the base. The bridge functions as a rigid superstructure to which working components of the lithography system 10 such as an optical projection system 108 and sensor platform 148 are attached. The projection system 108 is positioned between the two legs of the bridge 104 near the back of the system, and the sensor platform 148 is supported as a cantilever at the horseshoe's base near the front of the system. A working region 112 is defined as a region beneath the bridge and alignment station but over the base.

Substrates 114 are transported in the working region 112 on preferably two stages 116. The stages 116 have linear motors that interact with a planar platen 118 that is formed over the surface of the base 100 to propel the stages over the base between an alignment station 120 and a projection station 122. The stages are supported above the platen on air bearings.

Fig. 2 shows an exemplary stage 116 on the base's platen 118. Platen 118 has an upper surface formed of a series of aligned and equally spaced ferromagnetic teeth 124 with non-magnetic material, such as epoxy filler 125, in the interstices between the teeth. The platen 118 is lapped to provide a smooth, upper surface. The teeth 124 are arranged in rows running in the y-direction and columns running in the x-direction. The teeth are square, of a uniform width and length of a few millimeters, and spaced from one another an equal distance.

The stages 116 are each propelled by four linear motors (shown in phantom), two motors 126, 128 for movement of the stage in the y-direction; and two motors 130, 132 for movement of the stage in the x-direction. Pairs of x-

motors and y-motors, are used to control rotational, θ. Motors 126 and 128 work in conjunction with columns of teeth running in the x-direction; and motors 130 and 132 work in conjunction with the rows of teeth running in the y-direction.

Platen-stage sensors 134 and 136 are associated the y-direction linear motors 126 and 128; and sensors 138 and 140 are associated with the x-direction linear motors 130 and 132. The sensors serve to determine the position in the x- and y-direction, and degree of rotation, of the stage 116 with respect to the platen 118 by detecting the teeth the stage passes over in the x- and y-directions. This system including the linear motors, position sensors, and platen are more completely described in U.S. Pat. Appl. Ser. No. 08/560,393, filed on November 17, 1995, by Craig Simpson, entitled Platen for Use with Lithographic Stages and Method of Making Same, the teachings of which are incorporated herein in their entirety by this reference.

1. Alignment Station

Returning to Fig. 1, the alignment station 120 of the working region 112 is where the substrates 114 are loaded into and unloaded from the lithography system 10. Additionally, the newly-loaded substrates are remotely aligned here by determining the position of the substrates 114 on the stages 116.

Associated with the alignment station are a supply 140 of substrates waiting to be exposed, an acclimation platform 142, and a storage 144 for exposed substrates. New substrates are first extracted from the supply 140 by a r-θ-z robot 146. This robot has an arm that 1) is extendable radially, 2) pivots, and 3) translates in the vertical (z) direction. The new substrates are placed on

the acclimation platform 142, which ensures that the entire substrate is at a constant temperature that is matched to the temperature of the lithography system 10. The substrates are then moved to the stage 116 after the exposed substrate, which has just returned from the exposure station, has been placed in the storage 144 by the robot 146.

Four different types of sensor-detectors are used to align the substrates 114 that have been placed on the stages 116 at the alignment station 120. A stage position detection system includes a stage homing system that is used to control the linear motors to move the stage to a predetermined, reproducible position. This home position represents the origin of the alignment station's coordinate system and is defined relative to the sensor platform 148, which is an INVAR® plate. Once at its home position, movement of the stage in the coordinate system is determined by a displacement detector system that is comprised of a series of interferometers 150, 152, 154. The two final systems are used to detect the position of the substrate 114 relative to the sensor plate 148, thus also locating the substrate 114 in the coordinate system. A fine substrate alignment system is used to detect the substrate's position by detecting alignment marks 156 that have been formed on the substrate 114. However, before this system may be activated, a coarse substrate alignment system is employed to both: 1) correct for any gross rotational error of the substrate 114 on the stage 116 which is too large to compensate for utilizing a limited ability of the stage 116 to rotate on the platen 118; and 2) coarsely detect the substrate's position on the stage so that the stage may be moved to locate alignment marks 156 within the capture range of the fine substrate alignment system.

The stage homing system at the alignment station is preferably based upon a pair of TAS projectors 158,160 and detectors 162, 164, 166. The two TAS projectors 158,160 are magnetically attached to the sensor platform 148, and the TAS detectors 162, 164, 166 are located in two metrology blocks 168, 170 on the stages.

The two TAS projectors 158,160 are spaced from each other by a distance that is equal to the distance between the first and the third TAS detectors 162,166. The response of the first TAS detector 162 is used to locate the stage 116 along the x- and y-axes. The response of the third TAS detector 166 is used to control angle θ of the stage. These two detectors are used instead of the second TAS detector 164 because they maximize the degree to which the rotational angle θ of the stage 116 can be controlled. The angle θ of the stage 116 is measured by determining the displacement at the third TAS detector 166. By maximizing the distance between the TAS detectors, displacement is maximized for a given stage angle θ, thus allowing the angle to be controlled with greater accuracy.

Returning to Fig. 2, the three TAS detectors 162, 164, 166 are located along the rear edge of the stage 116. The first and second TAS detectors 162,164 are located relatively near each other in a first metrology block 168 on the right half of the stage, and the third TAS detector 166 is located near the stage's left side in a second metrology block 170.

With reference to Fig. 3, each of the TAS detectors 162, 164, 166 comprises a quad-cell photodetector 172. Each cell 174 is preferably square. The cells 174 are arranged in a square pattern with a gap 176 between adjacent edges of the cells. A sensor reticle 178 is

positioned above the quad-cell photodetector 172. The sensor reticle is predominantly opaque to block off most the light to each quad cell. Only four rectangular portions 180 are transmissive. The sensor reticle 178 is centered over the quad-cell 172 in the metrology block 168 or 170 with each transmissive portion 180 being aligned over different photodetector 174. Thus, the sensor reticle 178 appears to be rotated 45° with respect to the quad-cell 172.

Each one of the TAS projectors 158,160 comprises a permanent magnet 182 that is used to attach the projector housing 159 to the sensor platform 148. The projector comprises an reticle illuminator 184 that shines light through a TAS projector reticle 186. Projection optics 190 are adjusted to form an image of the reticle 186 on the TAS detectors with no magnification.

The size of the projected image from the TAS projectors 158,160 is closely tailored to the arrangement of the transmissive rectangular portions 180 of the sensor reticles 178. The distance between centers of the rectangular portions 180 along both the y-axis and the x-axis is equal to the outer length and width of the projected image of the reticle 186. As a result, the electrical response of each of the photodetectors 174 of the quad-cell 172 is highly dependent upon the degree to which the projected image is centered over the sensor reticle 178. By moving the stage and thus the sensor reticle 178 so that the response of the opposing photodetectors is balanced, the stage can be repeatedly brought to the same home position to an accuracy of a few nanometers.

Returning to Fig. 1, the displacement detectors or interferometers of the stage position detection system measure movements of the stage from the home position at the alignment station 120. Preferably three interferometers 150,152,154 are used. Two 150, 152 are directed towards a first mirror 198 located on a vertical right side wall of the stage 116 and are used to the measure y-axis displacement and the stage's rotational angle θ. The third interferometer 154 operates in cooperation with a second mirror 200 that is located on the front side wall of the stage 116. The second mirror 200 may be smaller in its extent than the first mirror since only a single interferometer must be accommodated. The third interferometer 154 measures displacement along the x-axis.

The fine substrate alignment system comprises multiple dark-field type detectors 202, 204, 206, 208. In the preferred embodiment four are used, although a larger or smaller number of detectors may be desirable in some instances.

The dark-field detectors 202, 204, 206, 208 are constructed so that both the optics that project the image onto the substrate alignment mark 156 and the detection optics that detect the light that interacts with alignment mark are located together above the substrate. The design of the dark-field detectors is based upon earlier work disclosed in U.S. Patent No. 5,483,345, filed on September 6, 1994, by Donaher, *et al.*, entitled "Alignment System for Use in Lithography Using a Spherical Reflector Having a Center-Etched Projection Object," the teachings of this patent are incorporated herein in their entirety by this reference.

The Donaher, *et al*. patent discloses a device in which the optics that project the image down onto the substrate are located in an axial bore through the collection optics that capture light diffracted by a grating-type alignment mark located on the substrate. This early detector projected a cross pattern onto the substrate surface by directing light through a cross etched in the center of a spherical mirror from its back side. The light passing through the cross was directed down toward the substrate and then partially reflected back up to the spherical mirror by a 50/50 beamsplitter and then focused back down through the beamsplitter to the substrate. While yielding a diffraction-limited system, this early approach created a large halo of light on the substrate surrounding the projected cross pattern. The halo resulted from the light that initially passed through the etched cross and the beam splitter directly onto the substrate without ever being focused by the spherical mirror. Further, the process of etching the spherical mirror was difficult.

Further research has validated the basic design of dark-field sensor described Donaher, *et al*. patent but has lead to a simpler, less costly device. The improved alignment sensor is shown in Fig. 4A. Light is supplied from a source 210 that is common to all of the dark-field sensors. The light is conveyed to the individual sensors by a fiber optic cable 212. Illumination optics 214 receive the light. A fold mirror 216 then redirects the light down, toward the substrate and through a first lens 218, which concentrates the light to pass through a reticle 220.

Fig. 4B shows the reticle 220 for the dark-field detector. It is generally chrome plated to be

nontransmissive to light but has clear, light-transmissive cross at its center comprised of two perpendicular arms 224, 226 that form a cross pattern 222 on the substrate 114.

Returning to Fig. 4A, the light passing through the transmissive portion of the cross reticle 220 is then imaged down on the substrate 114 by refractive projection optics 228. The projection optics 228 are preferably comprised four lenses in a symmetrical double Gauss configuration. This configuration yields an image quality which is as good or nearly as good as that formed by the spherical mirror in the earlier design. The improved operation, however, lies in the fact that the spherical mirror with the 50/50 beamsplitter had a light throughput of only 25 percent due mostly to the light lost in the halo. In contrast, the throughput of the optics of the present invention is greater than 90% since all of the light that passes through the cross reticle 220 is imaged onto the substrate 114 except for losses in the refractive optics 228.

Collection optics 230 capture the diffracted light from the imaged cross pattern on the grating alignment marks 156 of the substrate 114. In the preferred embodiment, the collection optics 230 comprise four lenses concentrically surrounding the projection optics. The projection optics 228 are located in a concentric bore 232 formed through the collection optics 230.

The collection optics 230 only collect diffracted light from the cross pattern. Any light that is simply reflected from the substrate 114 does not enter the collection optics 230, being reflected back up through the projection optics 228 and lost. The diffracted light is

focused or imaged onto a photodetector 234. The photodetector preferably measures the magnitude of the diffracted light and generates a signal indicative of it.

The four dark-field detectors 202, 204, 206, 208 are arranged on the sensor platform 148 so that they are each positioned over a different alignment mark 156 of the substrate 114. The housing 231 of each sensor is held to the plate 148 by a permanent magnet 235. The position of the alignment marks is determined by simultaneously scanning the alignment marks of the substrate under the projected cross patterns from the dark-field detectors.

Fig. 5A shows an alignment mark 156 that is compatible with the simultaneous scanning used by the present invention. The mark 156 comprises two orthogonal gratings 234, 236 extending away from a square region 238. A bright field alignment mark 240 is located in this center region 238. Each line or tooth of the gratings is approximately 6 micrometers (μm) wide with a spacing of 36 μm between lines. In the center of each grating, a line is missing 252. The alignment marks preferably have a relatively large physical extent. The total length of the mark in both the x and y directions is preferably approximately 5.4 millimeters (mm).

Fig. 6 shows the level of diffracted light and thus the electrical signal output 242 of a dark-field alignment detector's photodetector 234 as either of the alignment mark's gratings 234,236 are scanned underneath the alignment detector by movement of the stage on the platen. The photodetector's response is at a maximum 244 as the leg of the cross 222, which is parallel to the lines of the grating, passes over an edge 246 of a line 248. The photodetector's response is at a minimum 250 whenever the

cross leg falls directly over a line or between lines causing most of the light to be reflected.

The alignment marks 156 are located in the coordinate system of the alignment station 120 by scanning the y-axis grating 234 and an x-axis grating 236 under the control of the interferometers 150, 152, 154. By comparing the detected grating location to the position information from the interferometers, the phase of the marks can be determined with great accuracy.

Many dark-field alignment systems operate by projecting rather complex images that are similar in size to the alignment mark. Both the projected image and the mark usually have orthogonally arranged gratings. The substrate is positioned under the projected image so that it is uniquely located at a point that maximizes the total amount of diffracted light. This type of system, however, is not preferred here as it would require that alignment of the substrate with respect to each of the sensors occur serially in time. The substrate could be aligned with respect to only a single alignment sensor at a time. In contrast, the present invention relies on scanning of the cross pattern 222 over the alignment marks which can occur for all the marks simultaneously.

Scanning the cross pattern over the gratings on the substrate has the additional advantage that much larger alignment marks on the substrate may be used, which increases the capture range of the system. The projected image can be much smaller than the alignment mark, however, allowing reasonably sized projection systems. Moreover, since the location of each line in the grating is separately determined, the system is much more accurate

since information from the entire scan may be used to determine the mark's location.

Figs. 5B shows another example of an alignment mark for the dark-field detector. In this example, the distance between the lines or teeth of the gratings 234, 236 continuously varies as a function of the position within the grating. The grating can be viewed as comprising two sets of lines, each with a different spatial period or frequency. The line-dense portions 254 of the gratings represent locations where the two sets of lines are out-of-phase with each other. The line-sparse portions 255 represent places where the sets of lines are in-phase with each other.

Returning to Fig. 1, the coarse substrate alignment system is used to correct large deviations in the substrate's angle θ on the stage and to ensure that the substrate's position is known with enough accuracy that alignment marks can be placed within the capture range of the dark-field detectors. The coarse substrate alignment system comprises three non-contact substrate edge detectors 258, 262, 264.

Each detector 258, 262, 264 comprises a light projector that casts a light spot down onto the top surface of the stage 116 and substrate 114. The light spot has a straight shadow line that is preferably perpendicular to the substrate's edge. This shadow line is created by a partial light stop on the output from a light source then using projection optics to image the light stop edge in the plane of the substrate and stage. The light from the projector is directed at an oblique angle α with regard to the plane of the substrate and stage. The optical axis of the projector, however, is substantially within a vertical

plane that passes through the substrate's edge. A camera, also substantially in the vertical plane including the substrate's edge, is positioned to detect the light that is diffusely reflected by the substrate and stage. The angle β of the optical axis of the camera with respect to the substrate and stage is slightly different than the angle α of the optical axis of the projector so that the camera does not receive the specularly reflected light from substrate stage.

The substrate's edge is detected by determining the location of a shift in the shadow line caused by the height difference between the substrate and stage. From the perspective of the camera, this shift appears as a jog in the otherwise straight shadow line. By using three non-contact edge detectors, two 258,262 which are used to detect the edge along the left side of the substrate, and one 264 which is used to detect the location of the front edge, the position and angle of the substrate may be determined.

Fig. 7A shows the construction of an exemplary one of non-contact substrate edge detectors 258, 262, 264 that has been constructed according to the principles of the present invention.

Each of the edge detectors 258, 262, 264 comprises a light projector 1134 that projects a field of light 1130 down onto a point of interest on the stage 116 and substrate 114. This light field illuminates both a section of the stage, a segment of the substrate's edge, and a portion of the substrate. The light field 1130 is bounded on at least one side by a predetermined edge pattern or shadow line 1132, beyond which there is no light. This

edge pattern 1132 is preferably a straight edge that is perpendicular to the substrate edge 1118, 1120.

A camera 1128 is positioned to detect the light field 1130 projected onto the substrate and stage. The camera 1128 includes an imaging lens 1146 that forms an image of the light field 1130 on a charged-coupled device (CCD) array 1148. For clarity, the superstructure that connects the projector 1134 and camera 1128 to the pre-alignment or alignment platform 148 is not shown.

Fig. 7B shows one embodiment of the projector 1134. An optical fiber 1136, transmitting light from a source not shown, has a proximal end that is partially blocked by a straight edge 1140 of a light stop 1142. A projection lens 1144 is used to form an image of the end 1138 of the fiber and straight edge 1140 on the plane of the stage 116. The optical characteristics should be chosen so that the image of the straight edge remain sharply focused through a vertical range large enough to encompass the top of the stage 116 and the upper surface of the substrate 114, taking into account any variability in the height of the stage.

Fig. 7C shows the region of the light field 1130 and shadow line 1132 that is detected by the camera 1128. Specifically, the field of view of the camera 1128 and its position are adjusted so that it views a rectangular region 150 extending across the shadow line. The long axis of the rectangular field of view 1150 is preferably parallel to the shadow line 1132. The field of view 1150 includes a section 1152 of the light field and a dark section 1154 that extends beyond the shadow line 1132.

Figs. 7D and 7E show the angular relationship between the projector 1134 and camera 1128. The optical axis 1154 of the camera 1128 extends from the point of interest 1156 at an angle β and preferably lies in a plane that is perpendicular to the stage 116 and that includes the nominal edge position 1118, 1120 of the substrate 114. The projector 1134 is also directed at the point of interest 1156. The optical axis of the projector 1134, while being near the perpendicular plane of the substrate edge, is angularly offset by a small angle θ. The resulting light field 1130 is elliptical and truncated by the straight shadow line 1132.

Because this edge detector 258, 262, 264 uses diffuse light and because the substrate 114, except for any bevel on its edge, is typically a specular reflector, the angle β should be set at either greater or less than the angle α. Also, the projector is shifted out of the vertical plane by the angle θ to move a penumbra out of the view of the camera. This penumbra can be created by light passing through bevels on the substrate's edges, and being diffusely reflected by the stage. The penumbra of light can otherwise blur the division between the dark and light along the edge of the substrate. Tilting of the projector by the angle θ shifts the penumbra so that it is no longer seen from the perspective of the camera.

Fig. 7F shows a top view of the light field 1130 and shadow line 1132. The effect of the substrate's height above the stage has the effect of shifting the portion 1158 of the shadow line 1132 that impinges on the substrate 114 towards the projector 1134 and away from the camera 1128. A step or jog 1160 is created due to this discontinuity.

The side view of Fig. 7G shows how the step effect is created. The incoming light beam 1162 from the projector 1134 has a top edge that is defined by the shadow line 1132. The effect of the substrate 114 is to shift the shadow line 1158 that falls on the portion of the substrate 114, in this case upward, by an amount D which is proportional to the thickness of the substrate 114.

Fig. 7H shows the light field 1130 within the camera's field of view 1150. The image is similar to the top view of Fig. 7F except that the step 1160 is somewhat larger due to the camera's inclination. Of note is the fact that the portion of the substrate above the shadow line is dark. This is due to the fact that the differing angles α and β of the projector 1134 and camera 1128, respectively, that do not allow specularly reflected light into the camera.

A diffusively reflecting, opaque substrate would have the effect of brightening the area on the substrate above the shadow line 1158.

The controller 1129 receives the image shown in Fig. 7H as pixel picture information from the cameras 1128. The controller 1129 uses a defined horizontal band 1159 that runs perpendicularly to the substrate edge 1118, 1120 and contains an illuminated portion of the stage 116 on one side and a shadowed portion of the substrate 114 on the other. One picture processing technique that allows the controller 1129 or system controller described later to pick out the location of the edge 1118, 1120 is to sum each pixel column, see reference numeral 1161 for example, within the horizontal band 1159. The intensity verses spatial position plot in Fig. 7I represents the intensity of the summed pixel columns across the horizontal band 1159. The edge is indicated by the pixel columns that

exhibit a sharp drop in intensity. The advantage of summing pixel columns rather than analyzing a single row of pixels is that a single pixel error will not cause an error in position.

The controller 1129 locates the position of the edge 1118, 1120 in the x-axis by finding the location of the sharp drop in intensity 1163 representing the change from the illuminated portion of stage 116 to the shadowed portion of the substrate 114. Since the edge detection optics are precisely located, the position of the edge is then known. The substrate can be moved to a position within a capture range defined by the length of the shadow line 1132 within the camera's field of view.

Fig. 7J shows a side view when the light field 1130 is projected onto a transparent substrate 114. The incoming light 1162 from the projector, bounded on the top by the shadow line 1132, strikes the top planar surface 1164 of the transparent substrate 114 and is refracted downward at a steeper angle due to the higher index of refraction of the substrate 114 relative to the air. The light passing through the substrate 114 is diffusely reflected back upwards by the stage 116.

As shown in Fig. 7K, the position of the shadow line 1132 from the perspective of the camera is still shifted upward but simply not to the degree that occurs with opaque substrates. Thus, for a horizontal band 1159 of the camera's image, there is still a portion of the substrate edge 1118, 1120 that bounds an illuminated area on one side and a dark area on the other. Note, that in contrast to the specularly reflecting substrate, there is now an area 1172 of the substrate above the shadow line section 1158 from the perspective of the camera that is illuminated due

to the combined effect of the transparency of the substrate 110 and the diffuse reflection from the stage 116.

As shown in Fig. 7L, substrate edges 1118, 1120 come in a number of forms other than the right edges discussed above. Commonly, the edge of the substrate is beveled 1174. Fig. 7M shows the shadow line for the substrate with beveled edge. A portion of the shadow line crossing the bevel 1176 is inclined downwardly at an angle related to the angle of the bevel 1174. The vertical edge of the bevel, however, still leaves a horizontal band 1159 containing a portion of the substrate defined by the shadow on one side and the light on the other.

The information from the non-contact edge detectors 258, 262, 264 is used to correct for any large errors in the rotation θ of the substrate 114 on the stage 116. Referring back to Fig. 2, two pivot pins 270,272 are provided on the top surface of the stage 116. The pins have concentric suction ports that grab the substrate from below. Once the substrate is held, the flow of air in stage surface suction ports 269, which are usually used to hold the substrate to the stage, is reversed. This creates an air bearing underneath the substrate. The pins are then shifted in opposite directions with respect to each other to effect rotation of the substrate 114. For example if the substrate were to be rotated the clockwise direction, the first pin 270 is moved in the positive x direction, and the second pin 272 is moved in the negative x direction. Once the substrate is repositioned, the substrate is again suction held onto the stage.

Information from the stage homing system and interferometers is used to control the positioning of the stage by its linear motors. The fine substrate alignment

system of the alignment station is then capable of accurately and precisely determining the position of the substrate on the stage. More precisely, the positions of the stage and substrate are determined relative to the sensor platform 148. This is termed remote alignment since it is undertaken away from the projection system 108 and separated from it by a distance that need not be stable or known with great accuracy. This factor distinguishes it from off-axis alignment previously described where the relationship between the alignment sensor and the projection system is known and very stable.

2. Projection Station

The projection system 108 functions to form a desired image, usually recorded on a reticle, on the substrate's photoresist layer. The system's illuminator 280 comprises an mercury arc bulb. Appropriate filtering, not shown, is provided to obtain substantially only the g-line (436 nanometer (nm)) of the bulb's emissions. Also included are shutter and aperture blades (not shown) which control length of exposure and the size of the field, respectively. The light is directed downwardly to pass through a reticle 282 held on a horizontal reticle stage at an object plane. The stage may hold many reticles, each of which may be positioned under the light source as desired. After passing through the reticle, the light is reflected off of a first fold mirror 284 to enter a horizontally disposed optical system 286. The optical system is a doubly telecentric and reflective/refractive system having primary mirror 290 located behind a meniscus lens element 292. Light exiting the optical system is directed downward by a second fold mirror 294 onto the substrate 114 at the image plane.

The projection station 122 does not have separate TAS projectors, but instead relies on the projection system 108 to project the TAS patterns to home the stage. A portion 281 of the main reticle 282 in the projection system corresponds to the reticle of the TAS projectors described previously. During stage alignment, the aperture blades are used to limit the field to the portion that is used to produce TAS images. These images are projected down onto the first and second TAS detectors 162, 164 of the stage 116.

Of note is the fact that the first and third TAS detector 162, 166 are used at the alignment station 120 whereas the first 162 and second TAS detectors 164 are used at the projection station 122. In both cases the first TAS detector 162 is used to position the stage in the x and y axes. The third TAS detector 166 is used at the alignment station 120 to control the stage angle θ. The second TAS detector 164 is used for this function at that projection station 122. This difference between the alignment and projection stations results from the fact that at the alignment station, the location of the entire region of the stage must be known since the entire substrate is being aligned, but at the projection station only the region of the stage in the image field must be known accurately. Since θ is measured by determining the displacement at a point distant of the first TAS detector, accuracy is increased by maximizing the distance between the TAS detectors used for positioning. These principles similarly apply to the homing of the stage at the projection station 122. There, the distance between the TAS detectors, however, is limited by the maximum size of the image generated by the projection system 108. That is, since the TAS images must be projected onto the TAS detectors simultaneously to home the stage, the TAS detectors must be

closer than the length of the maximum projectable image of the projection system. This factor limits the distance between the TAS detectors at the projection station.

The limitations on the distance between the TAS detectors limits the degree to which stage angle can be controlled at the projection station. But, angular accuracy is less critical at the projection station where only individual images, not the entire substrate, need to be aligned. The lesser accuracy does not undermine the stitching alignment accuracy of the lithography system. Even if a small angular error α_1 exists between the coordinate system at the alignment station and the coordinate system at the projection station, that error simply results in the slight tilting of each individual projected image. Each successive image has the same error in its angle. The images are still stitched together with only slight misalignment, and only a slight overlay misalignment occurs.

Three interferometers 296, 298, 300 are used to determine the position of the stage 116 once it has been homed. The first and second interferometers 296, 298 determine the x-axis displacement and stage angle θ. The third interferometer 300 at the projection station determines y-axis displacement. The interferometers 296, 298 are relatively closely spaced at the projection station 122. This configuration is based upon the requirement that both of the interferometers must "see" the rear mirror 199 of the stage 116 as the entire surface of the substrate 114 is positioned below the projection system 108 for various exposures.

The projection station has two auxiliary alignment systems. The first of these is a reflective alignment

system 310, which provides an alternative method of aligning a substrate. Auxiliary dark-field alignment sensor 312 is also located at the projection station 122 and is used during calibration of the alignment station sensors. When either of these projection station alignment systems are used, a fourth interferometer 314 is used to provide x-axis control.

3. Control System and Process of Manufacturing Substrates

Fig. 8 shows the control system for the photolithography system. A system controller 610 receives information from the TAS detectors (162, 164, 166), non-contact edge detectors (258, 262, 264), platen-stage position sensors 134, 136, 138, 140, dark-field alignment detectors (202, 204, 206, 208), and the interferometers. The system controller uses this information to control the stage linear motors (126, 128, 130, 132), substrate rotation pins (270, 272), and the projection system 108.

Figs. 9A and 9B illustrate the process for manufacturing or processing substrates according to the inventive remote alignment technique. The description begins at the point in the process where the substrate at the projection station has been completely exposed.

The stage 116 carrying the exposed substrate 114 moves to the alignment station 120 and is homed by the stage homing system in step 502. Simultaneously, the stage, originally at the alignment station 120, is moved to projection station 122.

The exposed substrate 114 is removed from the stage 116 by the robot 146 to storage 144 and new unexposed substrate is taken from the acclimation station 142 and placed on the stage 116 in step 504. The robot places the

substrate on pins 273 which are then retracted so that the substrate is lowered and vacuum held against the stage. The substrate may also be banked against pins in some embodiments as part of a prealignment process. At some point during the subsequent alignment process, a new substrate is moved from the supply 140 to the acclimation station 142.

Prealignment is then performed in step 506-510. This involves the use of the non-contact edge detectors 258, 262, 264 of the coarse substrate alignment system. In step 506, the stage positions the substrate under the edge detectors and the substrate's position and angle of rotation θ are determined. The rotational angle θ of the substrate on the stage must be corrected if the angle is too large. The stage 116 has only a limited ability to rotate on the platen 118. This restriction is due to the fact that the interferometers are used to detect the movements of the stage. If the stage rotates on the platen, then the light reflected by the mirrors 198, 199, 200 on the sidewalls of the stage will not be received back at the interferometers. The degree to which the interferometers will tolerate stage rotation is dependent upon the beam size of the light from the interferometers and the distance between the interferometers and the stage. Generally, the stage can only be rotated a few hundred microradians (μrad). As a result, the rotational error in the substrate on the stage must be corrected to less than the maximum ability of the stage to compensate for this rotational error by stage rotation.

Rotation of the substrate is changed by actuating the suction posts 270, 272. The posts grab the substrate from below and rotate it to correct for the detected angle θ in step 508.

The location of the substrate is then remeasured with the coarse substrate alignment system in step 510. If the rotation of the substrate was properly corrected in steps 506 and 508 only an x- and y- axis offsets are left. These values are used to determine how the stage 116 must be moved in order to position the alignment marks 156 under the dark-field sensors 202, 204, 206, 208 of the fine substrate alignment system.

In step 512, the process branches based upon whether or not there are alignment marks 156 already formed on the substrate. If the substrate is in its first exposure-development-processing cycle, no alignment marks have yet been formed on the substrate. As a result, overlay-type alignment is not critical since there are not yet any existing structures to which alignment is necessary. If this is the case, the substrate can be moved to the projection stage for exposure.

If alignment marks 156 are present, however, then the remote alignment process is used to detect the precise location of the substrate using the x- and y- axis offset information from the pre-alignment process. The alignment marks are located under the dark-field detectors in step 514.

The stage is moved under interferometer control to locate the alignment marks 156 of the substrate underneath the corresponding dark-field detector in step 514; and in step 516, the alignment marks are simultaneously scanned under the corresponding dark-field detectors 202, 204, 206, 208. Based upon the responses from each of the dark-field detectors and the interferometers 150, 152, 154, the location of the substrate 114 relative to the sensor platform 148 is determined. Thus, since the location of

the stage is also known, the alignment of the substrate on the stage is determined.

With this phase of the substrate processing complete, the stage 116 may be moved to the projection station 122 in step 518. The movement to the station need not be precisely or accurately controlled, that is it need not be under the control of the interferometers. Instead, it can be accomplished by detecting movement of the stage relative to the teeth of the platen. During the movement, the substrate is rigidly suction-held using ports 269 to the stage so that the alignment of the substrate on the stage is not disturbed.

As this first stage is moved to the projection stations 122, the second stage holding the substrate for which exposure has been completed, moves to the alignment station 120. Once there, the robot 146 is used to remove the exposed substrate, move it to the substrate storage 144, and then bring in an entirely new substrate from the acclimation station 142. The alignment process may then be begun for that new substrate.

At the projection station 122, the stage is homed in response to the first and second TAS detectors 162, 164 in step 520. The stage position is adjusted until the responses from each of the opposed photocells of the quadcells are balanced. This location is the projection station home position.

The stage is then moved into the control of the interferometers to successively project stitched images across the face of the substrate in step 522 so that the desired pattern is formed on the substrate. Once this is completed, the process is repeated so that the exposed

substrate may be unloaded and a new unexposed substrate placed into the lithography system.

4. Extended Global Alignment

Fig. 10A shows the layout of the dark-field detectors 202, 204, 206, 208 relative to the substrate's alignment marks 156 according to the preceding-described arrangement. The alignment marks are not to scale but are shown enlarged for the purposes of illustration.

The dark-field detectors 202, 204, 206, 208 are located on the sensor platform 148 so that they each can simultaneously detect the same grating 236 of their respective alignment marks 156. Each of the alignment marks are oriented in the same fashion on the substrate so that the other gratings 234 of the alignment marks 156 can also be simultaneously scanned.

As described earlier, during alignment mark detection, the stage 116 moves the substrate 114 so that the gratings of the alignment marks 156 are scanned underneath the cross patterns 222 of the respective dark-field detectors. In the illustrated example, scanning is occurring in the direction of the x-axis.

By scanning each alignment mark 156 along both of its orthogonal gratings, the location of the alignment marks and thus the substrate 114 can be determined in the coordinate system of the alignment station. The information from two alignment marks provides the position of the substrate on the stage and its angle θ. The information gained from scanning the other two alignment marks may be used to more accurately determine the substrate's location and angle, effectively increasing the signal-to-noise ratio in the substrate's detected position.

Alternatively, information from these alignment marks may be used to detect distortion in the substrate caused by processing and manipulation of the substrate.

Fig. 10B shows a modification in which six dark-field alignment detectors 650, 652, 654, 656, 658, and 660 are used to detect six corresponding alignment marks 156 on the substrate. The increase in the number of alignment marks provides for a concomitant increase in the accuracy to which the substrate's position is detected and the types of substrate distortion that may be detected.

The increase in the number of alignment marks is required for larger flat panel displays. The larger sheets of glass or similar material are more prone to distortion, and more images must be stitched to cover the substrate with the desired pattern. Additionally, finer circuit elements common in newer designs require more accurate alignment.

It should be noted, however, that even as the number of dark-field alignment detectors and alignment marks increases, the time to align is not substantially impacted, since aligning happens simultaneously for all the detectors.

Fig. 10C shows another embodiment of the dark-field alignment detectors system. In this system, there is not a one-to-one correspondence between the detectors and the alignment marks. Twice as many marks are present than detectors. Four alignment sensors 662, 664, 666, 668 are used to first scan alignment marks 156a, then the stage and substrate 114 are moved along the x-axis so that the dark-field alignment detector 662, 664, 666, 668 can scan a second set of alignment marks 156b. This embodiment, while

increasing the time to scan the alignment marks by a factor of two, allows the same four dark-field alignment detectors to detect the substrate to a much higher degree of accuracy, detecting the position at eight different places on the substrate 114.

5. Alignment Detector Repositioning

As described earlier, the dark-field alignment detectors and TAS projectors are held to the sensor platform 148 by permanent magnets located in the base of each of the housings, since the sensor platform is made out of INVAR®, which is ferrous material.

Fig. 11A, shows this basic configuration with the permanent magnet 235,182 being magnetically attracted to the sensor platform 148 so that the housing 231,159 for the generically shown alignment element is therefore attached to the sensor platform 148.

Fig. 11B shows how the elements may be moved. As stated previously, their positioning is critical to ensure proper location relative to the stage. The same lithography system, however, must be adaptable to different alignment mark configurations, substrate sizes, and stage configurations. Repositioning to accommodate these situations is accomplished by connecting a source 20 of pressurized air to ports 710 on the side of the housing. A series of holes 712 are provided in the housing base, so that air will exit through these holes and create an air bearing 714 in concert with the magnetic loading. With the establishment of this air bearing, the alignment detector may be easily moved along the bottom surface of the sensor platform 148. Once being properly located, the source 20 of the pressurized air is removed, removing the air bearing

714. As a result, the element is again rigidly connected to the platform **148**.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

CLAIMS

What is claimed is:

1. A remote alignment system for a lithography tool, the system comprising:

at least one stage which transports substrates;

an alignment station at which the position of the substrates is determined relative to the stage; and

a projection station, which is remote from the alignment station and at which the stage is moved relative to a projection system to successively expose portions of the substrates.

2. A remote alignment system as described in Claim 1, comprising at least two of the stages, so that alignment information can be determined for a substrate on one stage at the alignment station while a substrate on the other stage is being exposed at the projection station.

3. A remote alignment system as described in Claim 1, further comprising:

a platen; and

a motor system that moves the stage over the platen.

4. A remote alignment system as described in Claim 3, further comprising a platen-stage position detection system which coarsely determines a position of the stage on the platen.

5. A remote alignment system as described in Claim 4, wherein the stage moves between the alignment station and the projection station only in response to the platen-stage positioning system.

6. A remote alignment system as described in Claim 3, wherein the alignment station comprises:

a stage position detection system that determines a location of the stage in a coordinate system of the alignment station; and

a substrate alignment system that detects a location of the substrate by reference to alignment marks on the substrate.

7. A remote alignment system as described in Claim 6, wherein the stage position detection system comprises

a stage homing detector that enables the stage to be moved to a home position in the coordinate system of the alignment station; and

a displacement detection system that measures movements of the stage within the alignment station coordinate system.

8. A remote alignment system as described in Claim 7, wherein the stage homing detector comprises at least one transmission alignment sensor including a projector for forming a pattern on photodetectors located on the stage.

9. A remote alignment system as described in Claim 8, wherein the stage homing detector comprises two transmission alignment sensors, one for locating an element of the stage and one for determining an angle of the stage.

10. A remote alignment system as described in Claim 9, wherein the two transmission alignment sensors are positioned near opposite sides of the stage.

11. A remote alignment system as described in Claim 7, wherein the displacement detection system comprises at least one interferometer that measures changes in distances to mirrors located on the stage.

12. A remote alignment system as described in Claim 6, wherein the substrate alignment system comprises at least one alignment mark detector including:

a projector that forms an image on the alignment marks on the substrates; and

a photodetector that detects diffracted light from the marks.

13. A remote alignment system as described in Claim 12, wherein the substrate alignment system comprises at least four of the alignment mark detectors that determine a location of and distortions in the substrates by the simultaneous reference to multiple ones of the alignment marks.

14. A remote alignment system as described in Claim 3, wherein the projection station comprises a stage position detection system that determines a location of the stage in a coordinate system of the projection station.

15. A remote alignment system as described in Claim 14, wherein the stage position detection system of the projection station comprises at least one transmission alignment detector on which the projection system forms a pattern.

16. A remote alignment system as described in Claim 15, wherein the projection station comprises two of the transmission alignment detectors, one for locating the stage and one for determining an angle of the stage.

17. A remote alignment system as described in Claim 16, wherein the projection system simultaneously forms patterns on both of the transmissive alignment detectors.

18. A remote alignment system as described in Claim 1, wherein the stage comprises a plurality of transmission alignment photodetectors which are used to home the stage at the alignment station and at the projection station.

19. A remote alignment system as described in Claim 18, wherein a distance between transmission alignment photodetectors used at the alignment station is related to a size of the substrate.

20. A remote alignment system as described in Claim 19, wherein a distance between transmission alignment photodetectors used at the projection station is related to a size of an image projected by the projection system.

21. A remote alignment system as described in Claim 18, wherein a greater distance exists between transmission alignment photodetectors used at the alignment station than between transmission alignment photodetectors used at the projection station.

22. A remote alignment system for a lithography tool, the system comprising:

a platen;

two stages which transport substrates;

a motor system that moves the stages over the platen;

a platen-stage position detection system which coarsely determines a position of the stage on the platen;

an alignment station at which positions of the substrates are determined relative to the stages, including:

a stage position detection system that determines a location of the stage in a coordinate system of the alignment station; and

a substrate alignment system that detects a location of the substrate by reference to alignment marks on the substrate; and

a projection station, which is remote from the alignment station and at which the stages are moved relative to a projection system to successively expose portions of the substrates and which includes a stage position detection system that determines a location of the stage in a coordinate system of the projection station.

23. A method for aligning and exposing a substrate on a stage of a lithography tool, the method comprising:

determining a position of the substrate relative to the stage at an alignment station;

transporting the substrate to a projection station on the stage;

successively positioning the stage at a series of locations at the projection station; and

exposing the substrate with the projection system when the stage reaches the locations.

24. A method as described in Claim 23, wherein the step of transporting the substrate to the projection station comprises only coarsely controlling a position of the stage when traversing between the alignment station and the projection station.

25. A method as described in Claim 23, further comprising simultaneously determining the position of one substrate on a first stage while exposing another substrate on a different stage.

26. A method as described in Claim 23, wherein the step of determining a position of the substrate relative to the stage comprises:

locating the stage in a coordinate system of the alignment station; and

detecting alignment marks on the substrate.

27. A method as described in Claim 26, wherein the step of locating the stage comprises:

moving the stage to a home position; and

measuring movements of the stage from the home position.

28. A method as described in Claim 23, wherein the step of transporting the substrate to the projection station comprises placing the stage at a home position for the projection station.

29. A method as described in Claim 28, wherein the step of successively positioning the stage comprises measuring movements of the stage from the home position of the projection station.

30. A method for exposing a substrate on a stage of a lithography tool, the method comprising:

transporting the stage into a capture range of an alignment station homing sensor;

positioning the stage in response to the alignment station homing sensor;

moving the stage at the alignment station in response to position detectors while locating alignment marks on the substrate;

recording a position of the substrate on the stage;

transporting the stage into a capture range of a projection station homing sensor;

positioning the stage relative to a projection system in response to the projection station homing sensor; and

moving the stage at the projection station in response to interferometers while exposing the substrate with the projection system.

31. A dark-field alignment detector, comprising

projection refractive optics for forming a pattern on an alignment mark;

collection optics for capturing light diffracted by the alignment mark, the projection optics being located in a bore in the center of the collection optics.

32. A dark-field alignment detector as described in Claim 31, wherein the alignment mark comprises orthogonal gratings.

33. A dark-field alignment detector as described in Claim 32, wherein the gratings having missing lines.

34. A dark-field alignment detector as described in Claim 32, wherein the gratings have a varying spatial line period.

35. A method for aligning a substrate, comprising:
forming multiple alignment marks on the substrate;
positioning the substrate so that the alignment marks are detectable by corresponding alignment mark detectors; and
scanning the substrate relative to the alignment mark detectors while simultaneously detecting information from multiple ones of the alignment marks with the alignment mark detectors.

36. A method as describe in Claim 35, further comprising:
forming alignment marks with orthogonal gratings; and
scanning each one of the gratings with the corresponding alignment mark detector.

37. A method as describe in Claim 35, further comprising detecting the alignment marks by projecting a pattern onto the alignment marks and detecting light diffracted by the marks.

38. A method for positioning and repositioning alignment elements on a substrate alignment platform in a lithography tool, comprising:

magnetically attaching the alignment elements to the alignment platform;

forming an air bearing between a base of the alignment elements and the platform;

repositioning the alignment elements on the air bearing; and

removing the air bearing when the alignment elements are properly positioned.

39. A substrate alignment system for a lithography device, comprising:

at least three substrate edge detectors, each detector being attached to an alignment platform above the substrate and a stage, each detector comprising:

a projector that projects a light field onto the substrate and the stage, the light field having a predetermined shadow line, and

a camera that detects light from the light field to generate an image of the light field; and

a controller that determines a location of the substrate by reference to the images from the cameras of the edge detectors

40. A substrate alignment system as described in Claim 39, wherein the controller determines the location of the substrate by identifying shifts in the shadow lines caused by a height differential between the substrate and the stage.

41. A substrate alignment system as described in Claim 39, wherein each of the projectors comprises:

a source of light having an aperture emitting light;

a light stop in front of the aperture that partially blocks the light from the aperture; and

projection optics that form an image of an edge of the light stop onto the substrate and stage to form the shadow line.

42. A substrate alignment system as described in Claim 39, wherein the optical axis of each projector lies near or in a plane that is perpendicular to the substrate and stage and includes an edge of the substrate.

43. A substrate alignment system as described in Claim 42, wherein the optical axes of the projectors are shifted slightly out of the planes.

44. A substrate alignment system as described in Claim 39, wherein optical axes of the cameras lie substantially in planes that are perpendicular to the substrate and stage and contain edges of the substrate.

45. A substrate alignment system as described in Claim 39, wherein angles of inclination of the projectors are different than angles of inclination of the corresponding cameras relative to the substrate and stage so that the cameras do not receive specularly reflected light from the substrate.

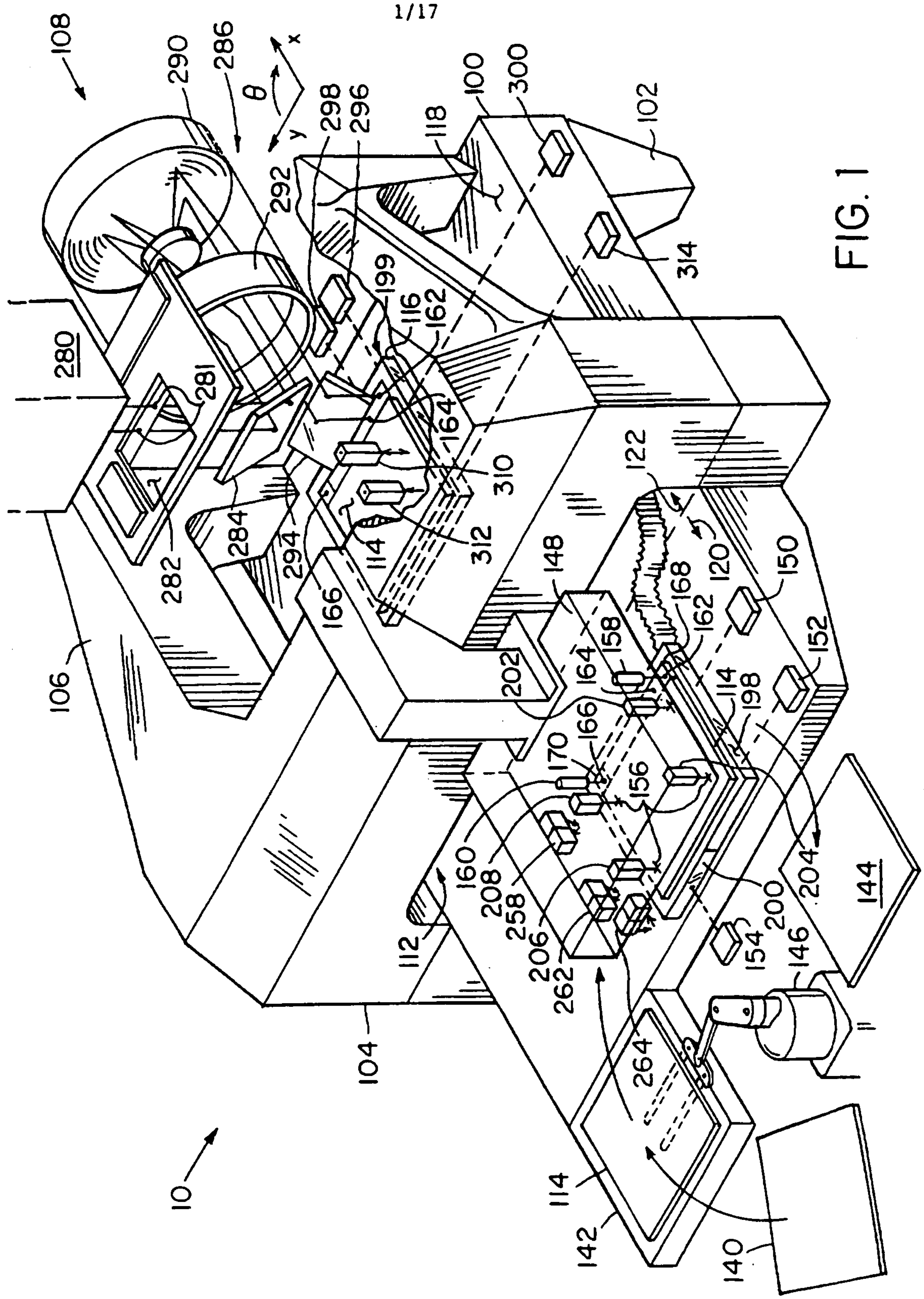
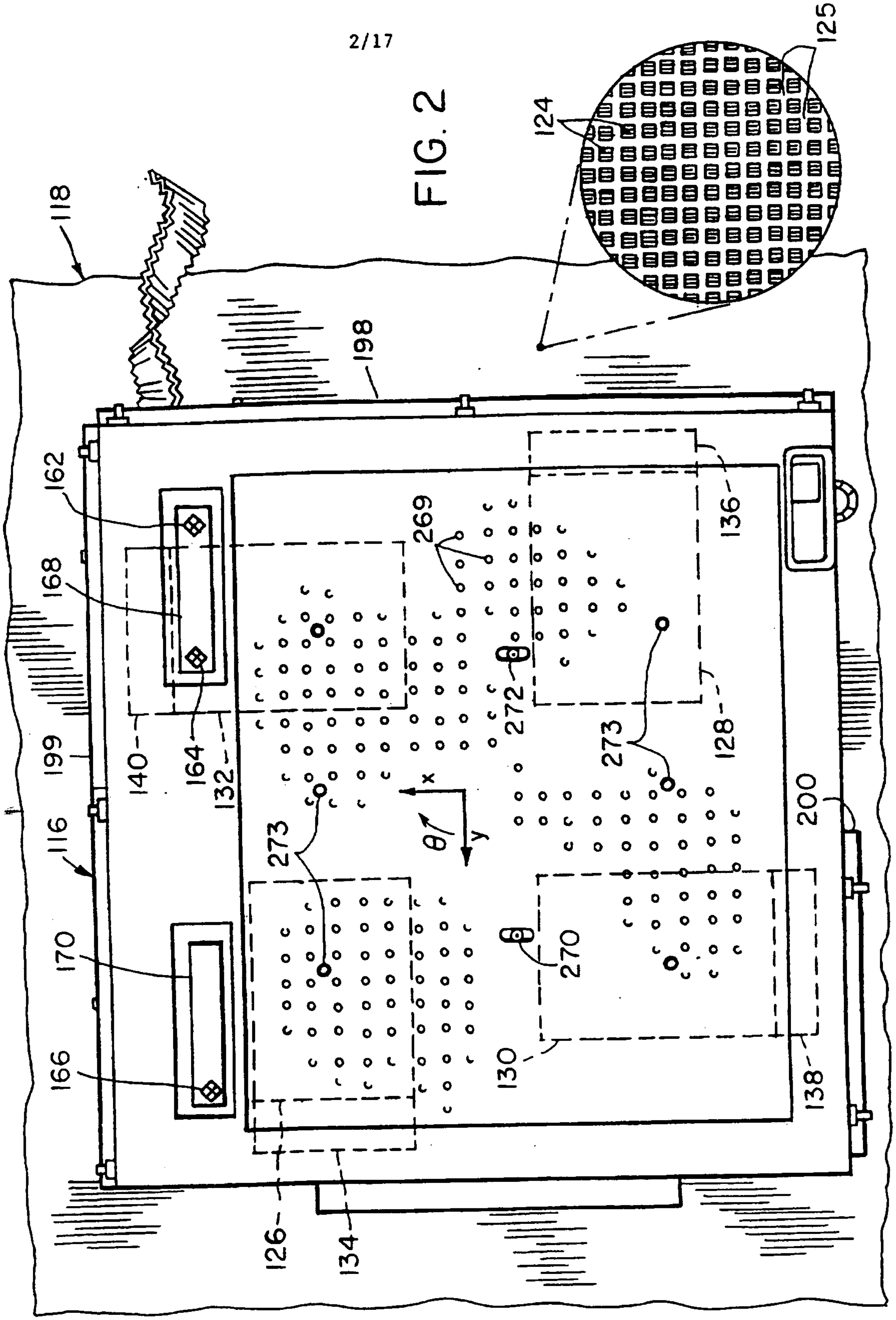


FIG. 1

FIG. 2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124
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162
168
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140
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269
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128
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200
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130
138
x
y
θ

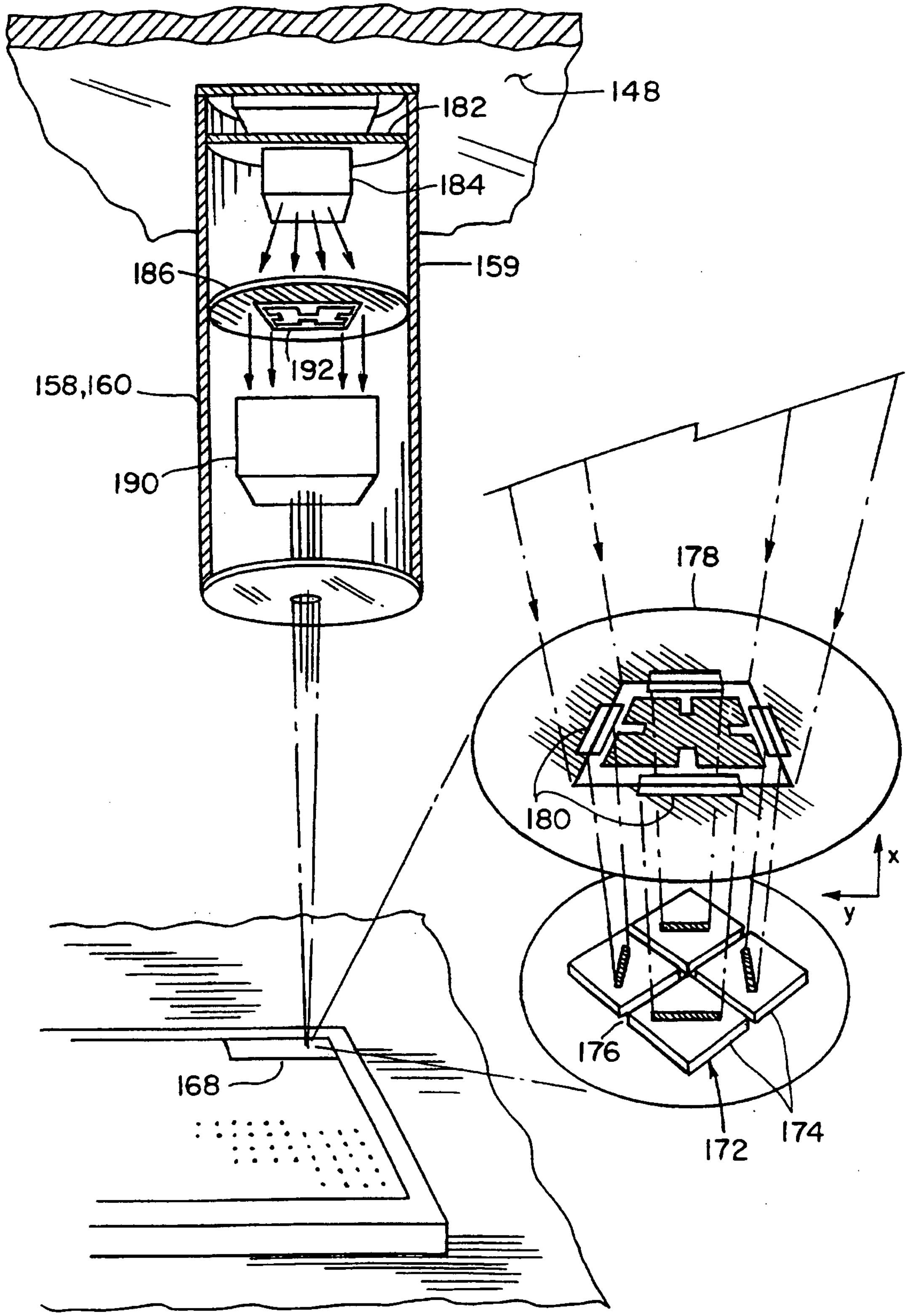
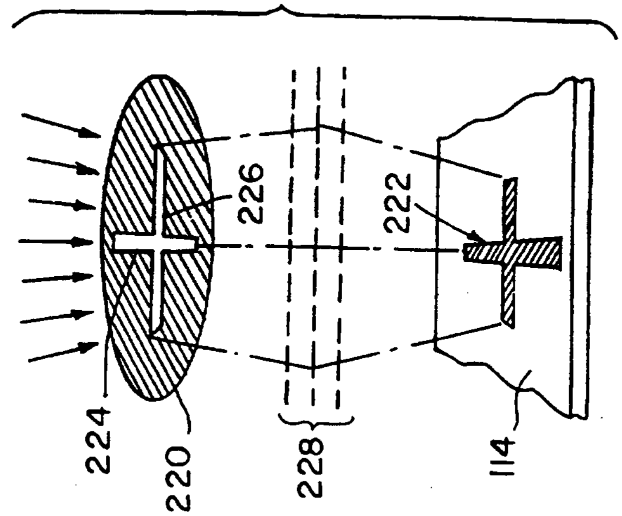


FIG. 3

FIG. 4B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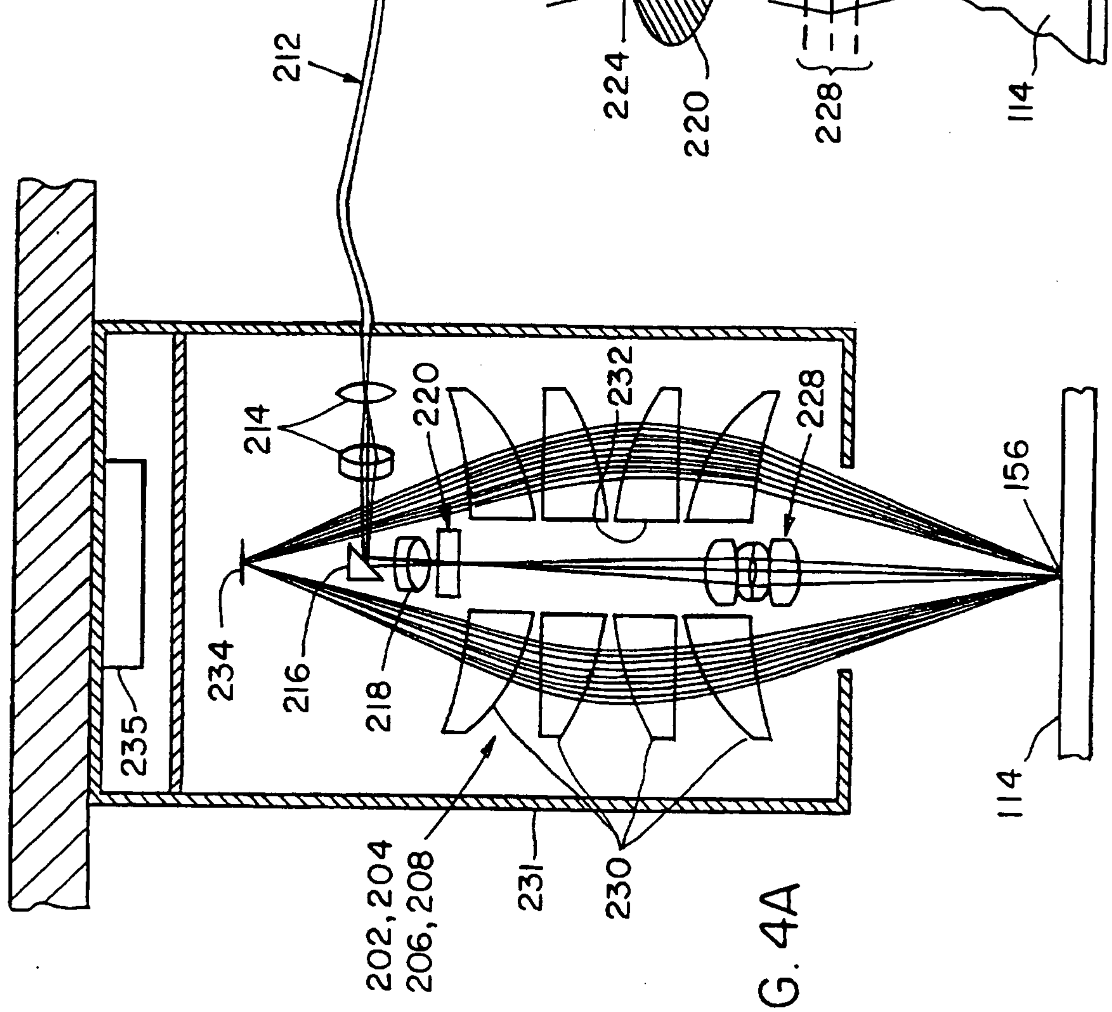
212
224
226
220
222
228
114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202, 204
206, 208
231
230
114

FIG. 4A

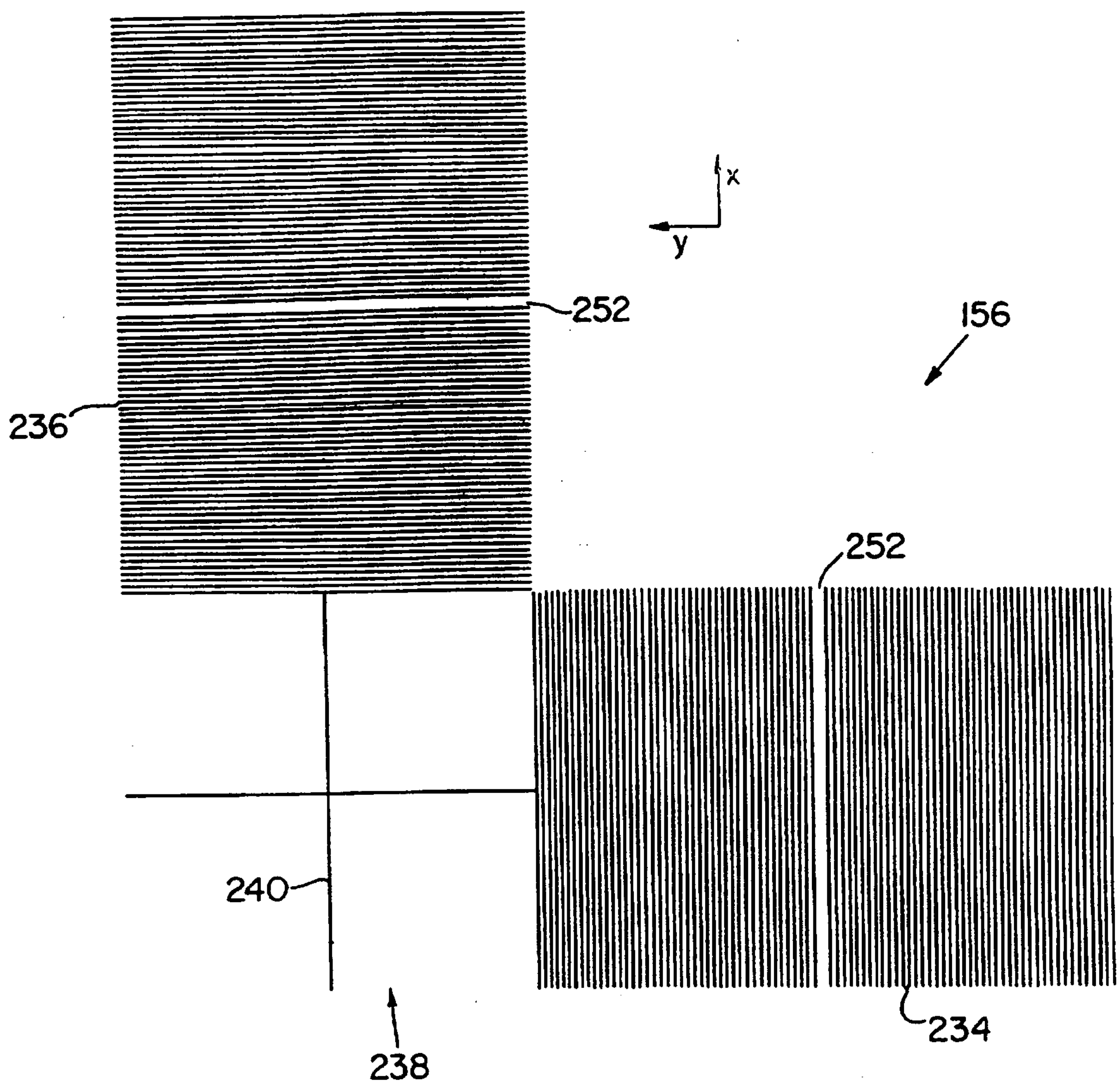
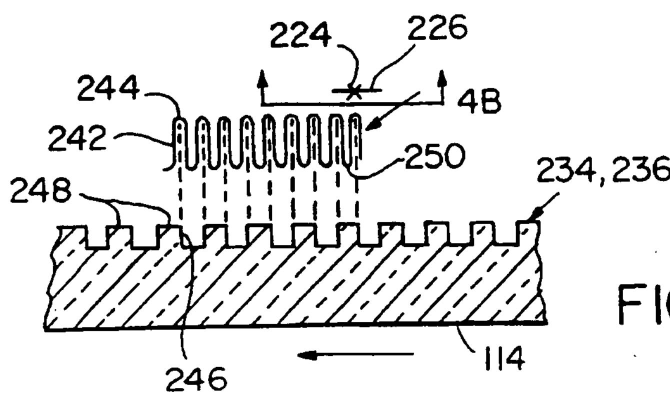

x
y
252
156
236
252
240
238
234

FIG. 5A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4B
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234,236
246
114

FIG. 6

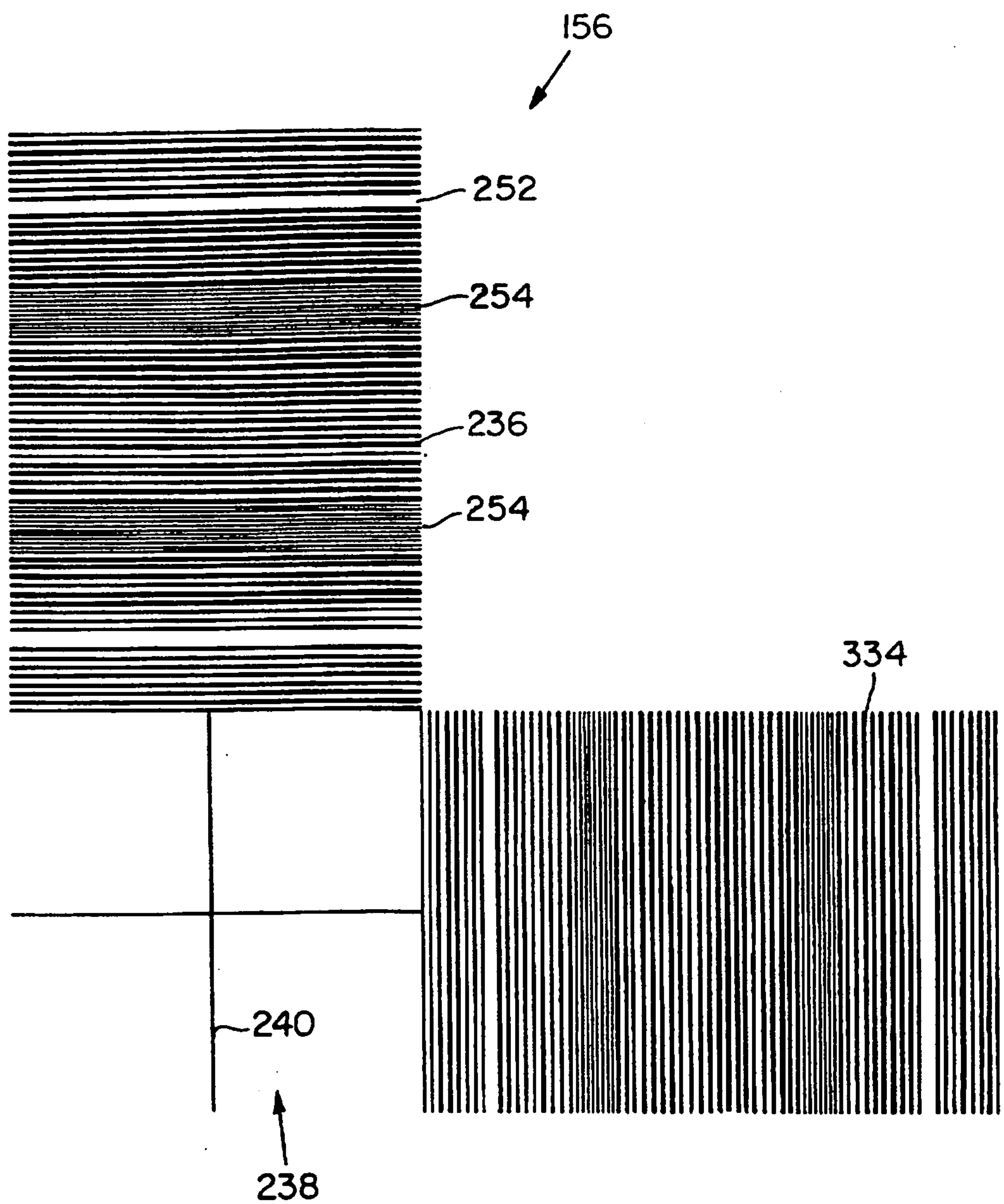


FIG. 5B

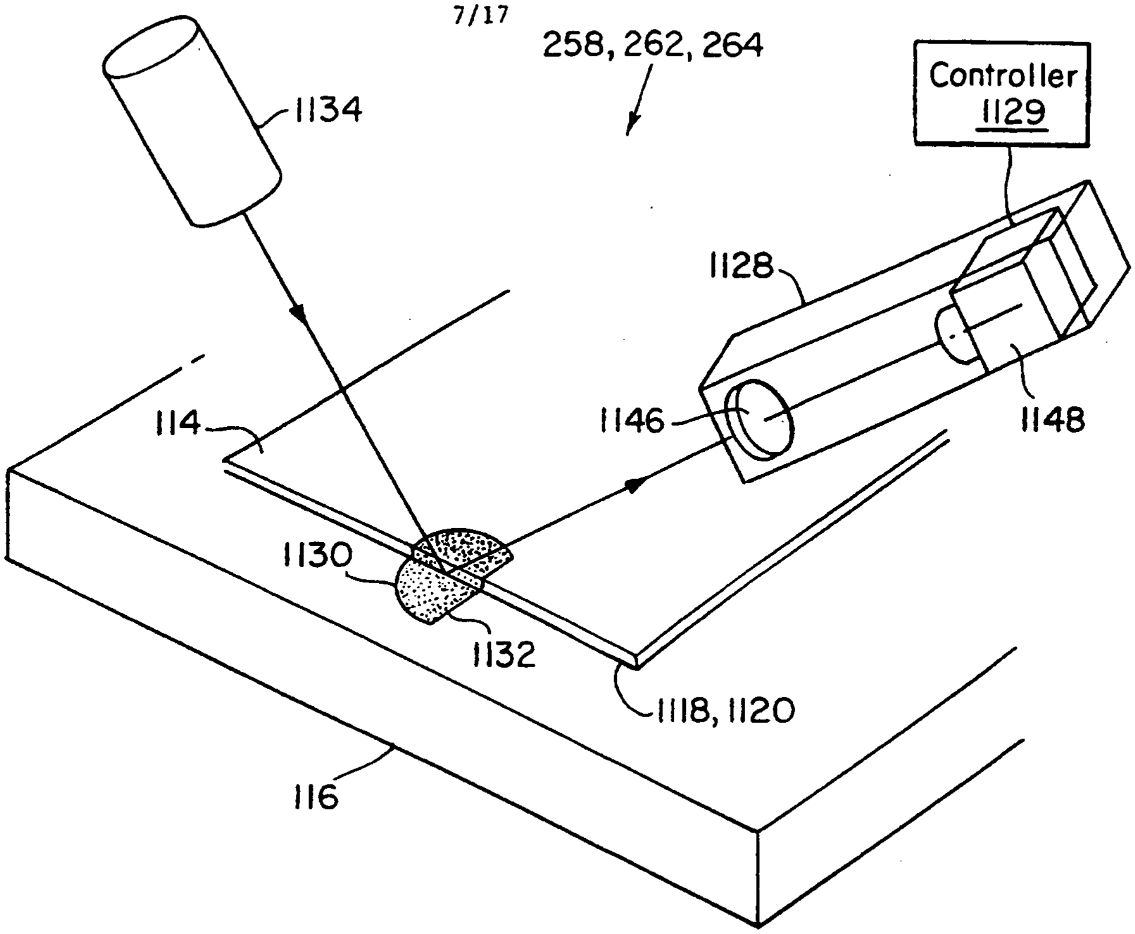
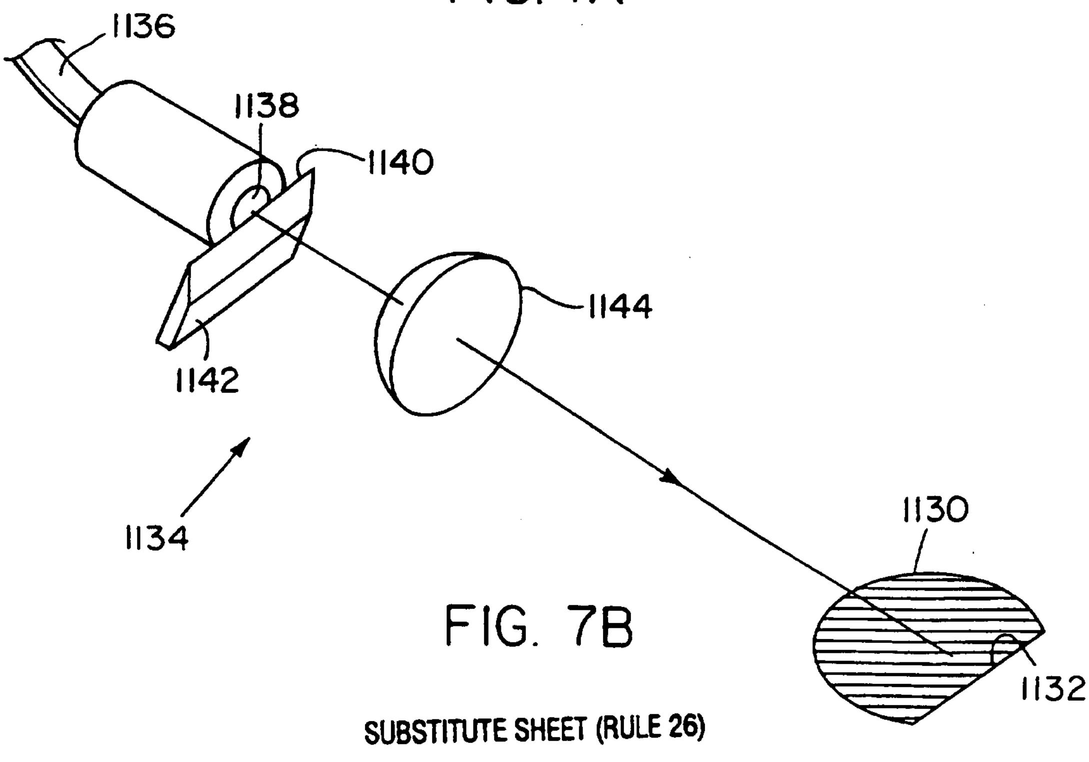

258, 262, 264
Controller
1129
1134
1128
1146
1148
114
1130
1132
1118, 1120
116

FIG. 7A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1132

FIG. 7B

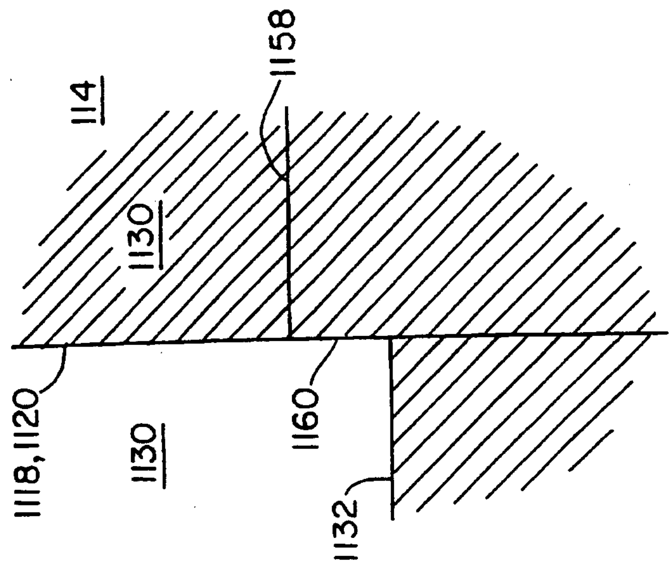


FIG. 7F

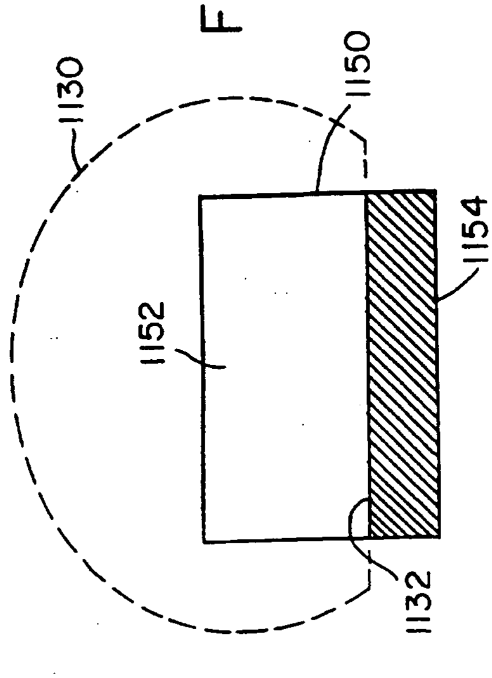


FIG. 7C

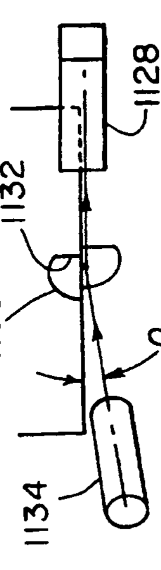


FIG. 7D

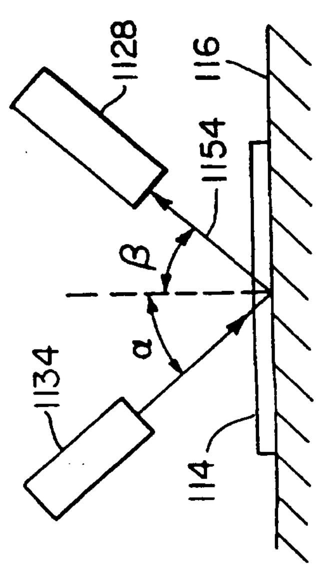


FIG. 7E

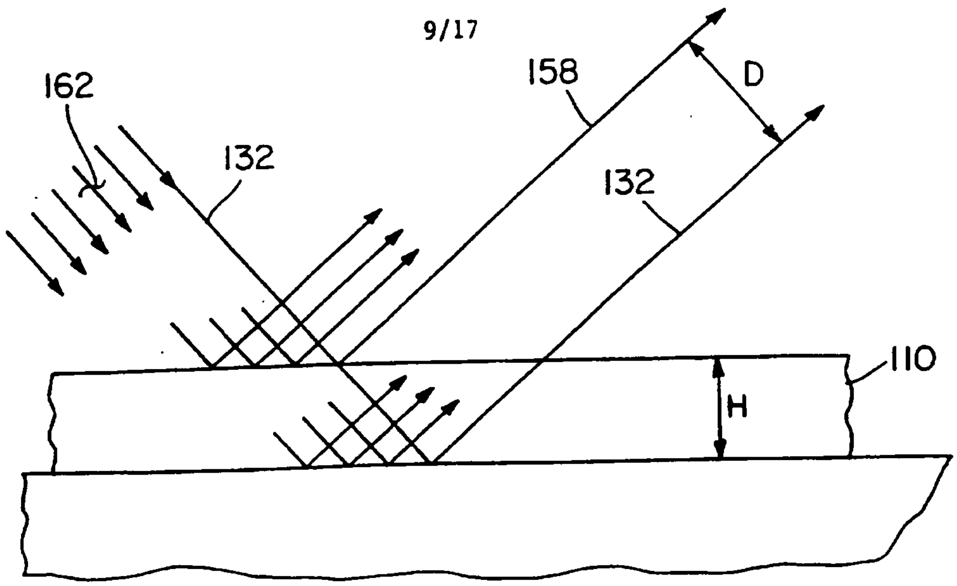


FIG. 7G

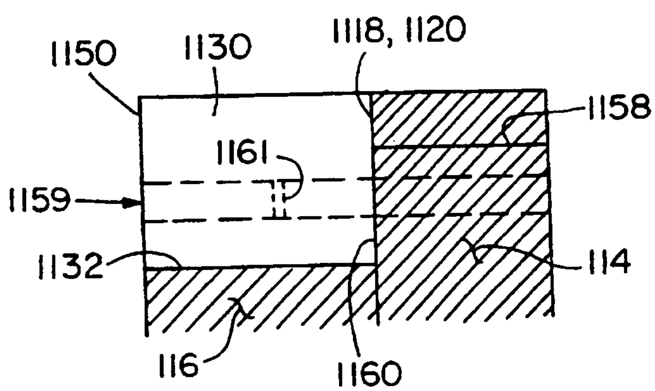


FIG. 7H

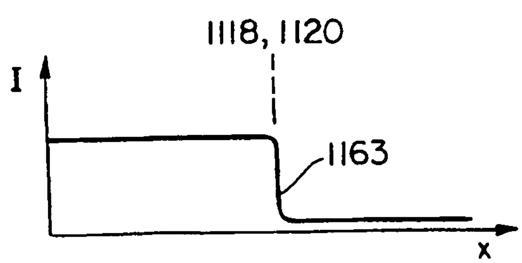


FIG. 7I

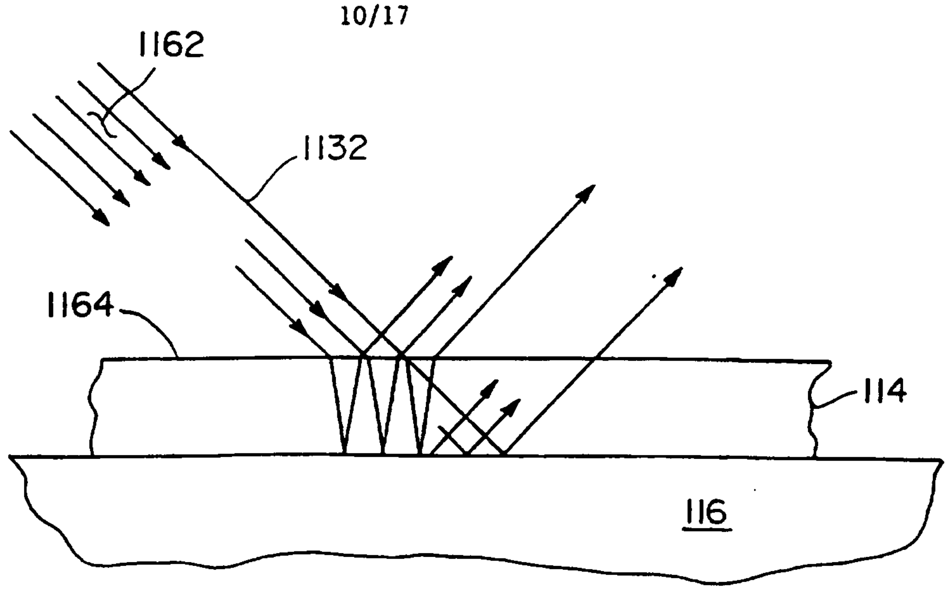

1162
1132
1164
114
116

FIG. 7J

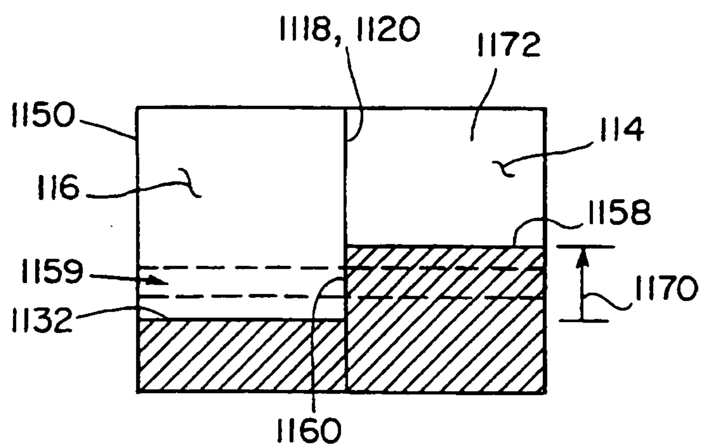
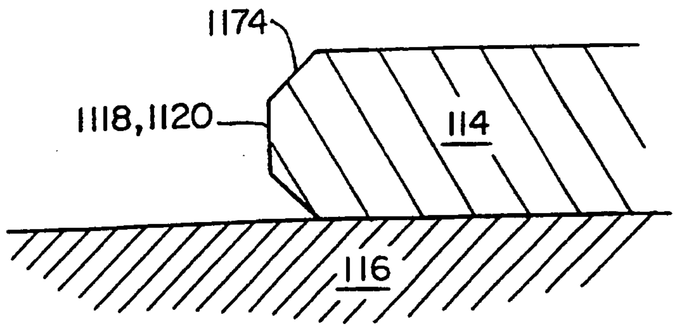

1118, 1120
1172
1150
114
116
1158
1159
1170
1132
1160

FIG. 7K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114
116

FIG. 7L

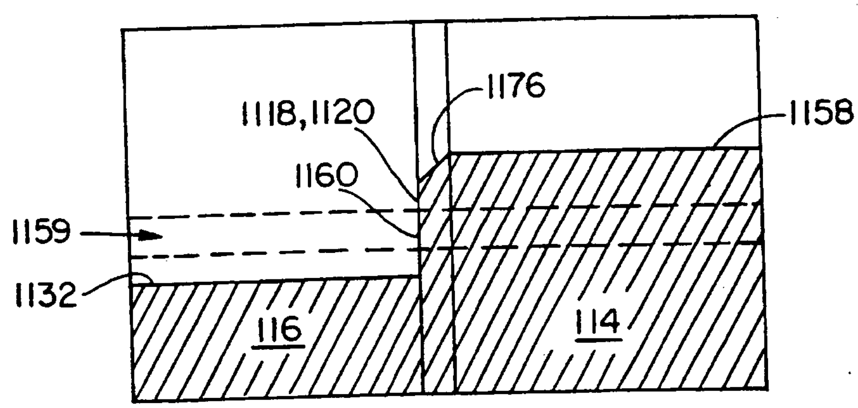

1176
1118,1120
1158
1160
1159
1132
116
114

FIG. 7M

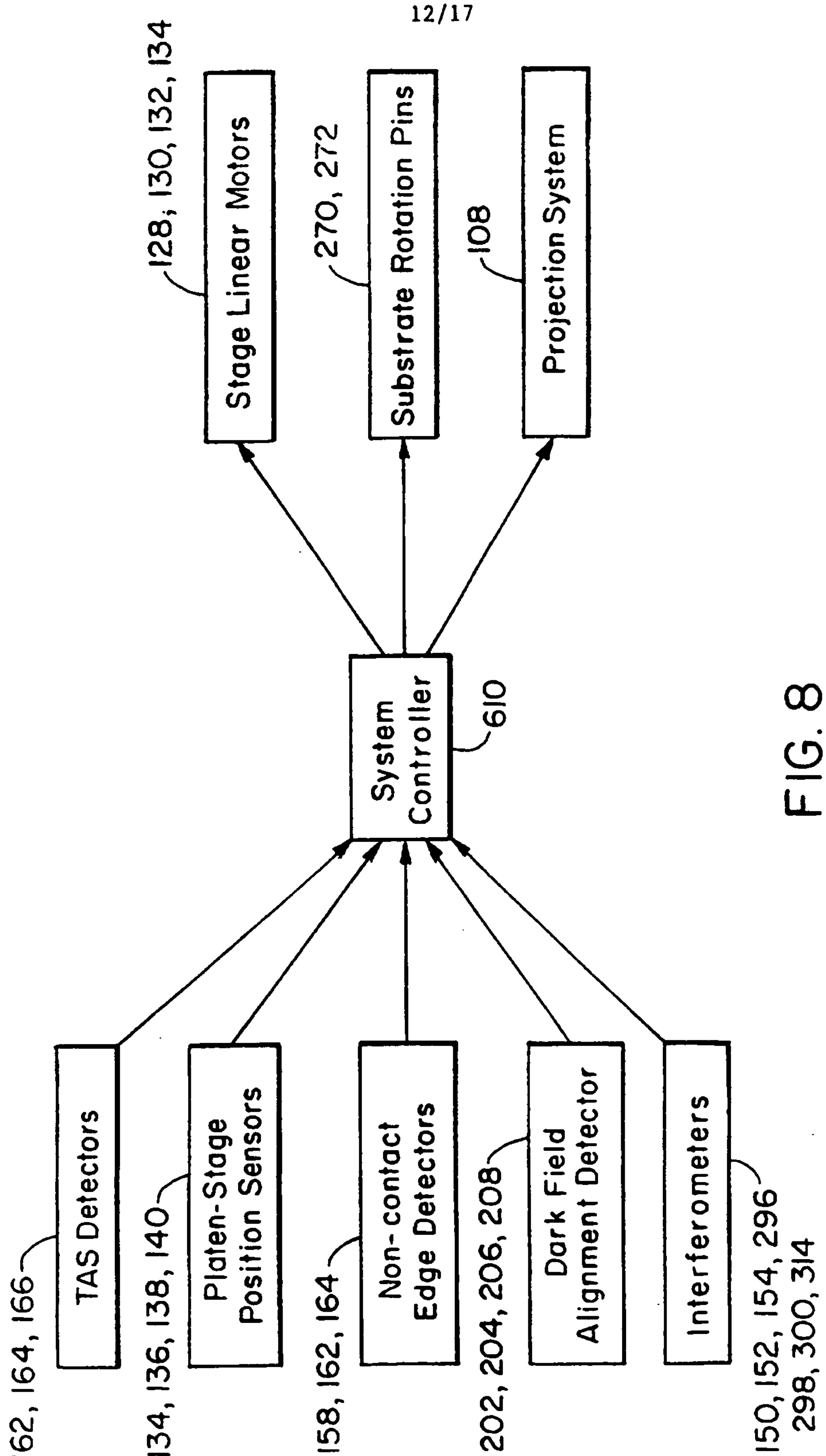
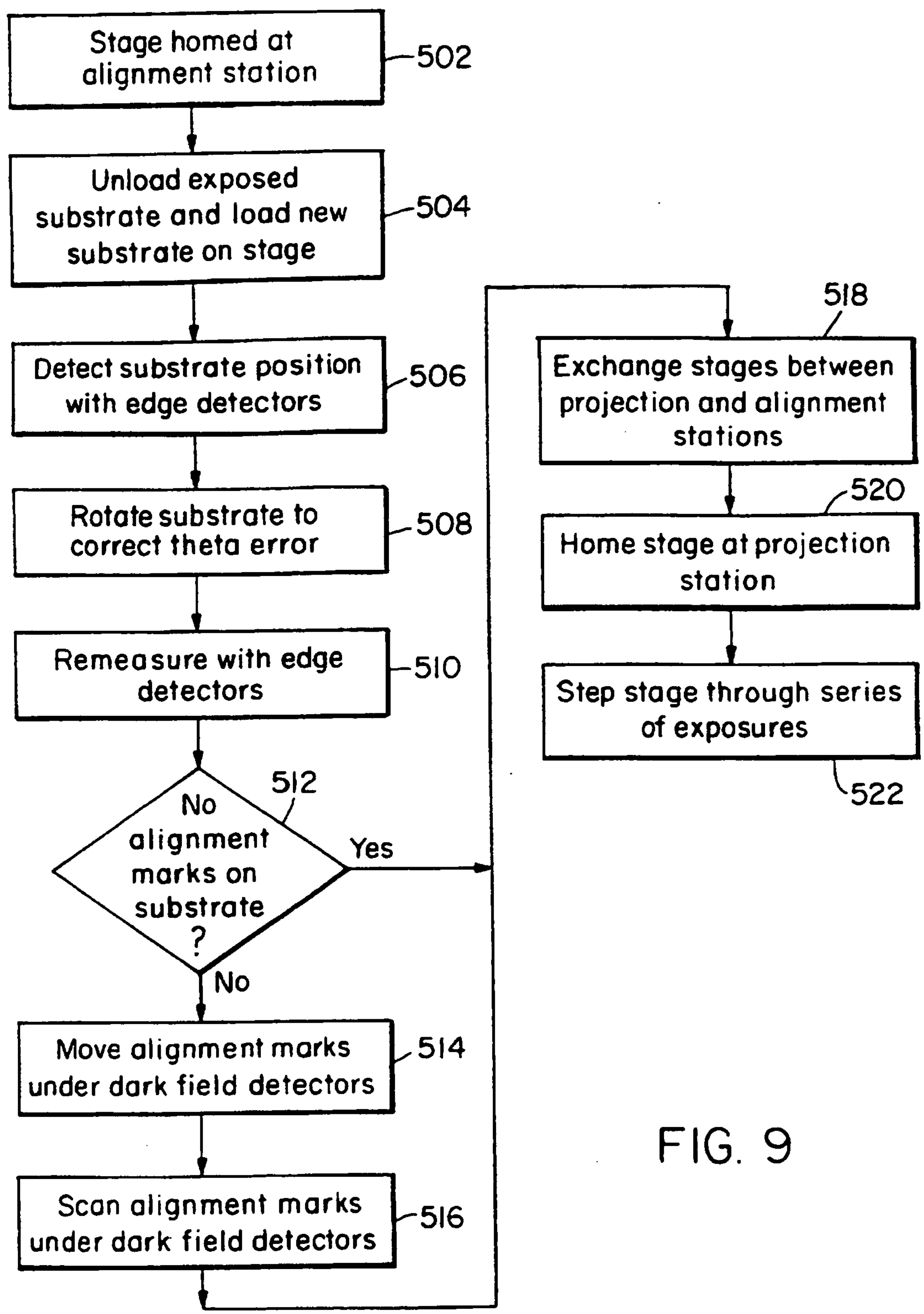

Stage Linear Motors
128, 130, 132, 134
Substrate Rotation Pins
270, 272
Projection System
108
System Controller
610
TAS Detectors
162, 164, 166
Platen-Stage Position Sensors
134, 136, 138, 140
Non-contact Edge Detectors
158, 162, 164
Dark Field Alignment Detector
202, 204, 206, 208
Interferometers
150, 152, 154, 296
298, 300, 314

FIG. 8



Stage homed at alignment station
502
Unload exposed substrate and load new substrate on stage
504
Detect substrate position with edge detectors
506
Rotate substrate to correct theta error
508
Remeasure with edge detectors
510
No alignment marks on substrate ?
512
Yes
No
Move alignment marks under dark field detectors
514
Scan alignment marks under dark field detectors
516
518
Exchange stages between projection and alignment stations
520
Home stage at projection station
Step stage through series of exposures
522

FIG. 9

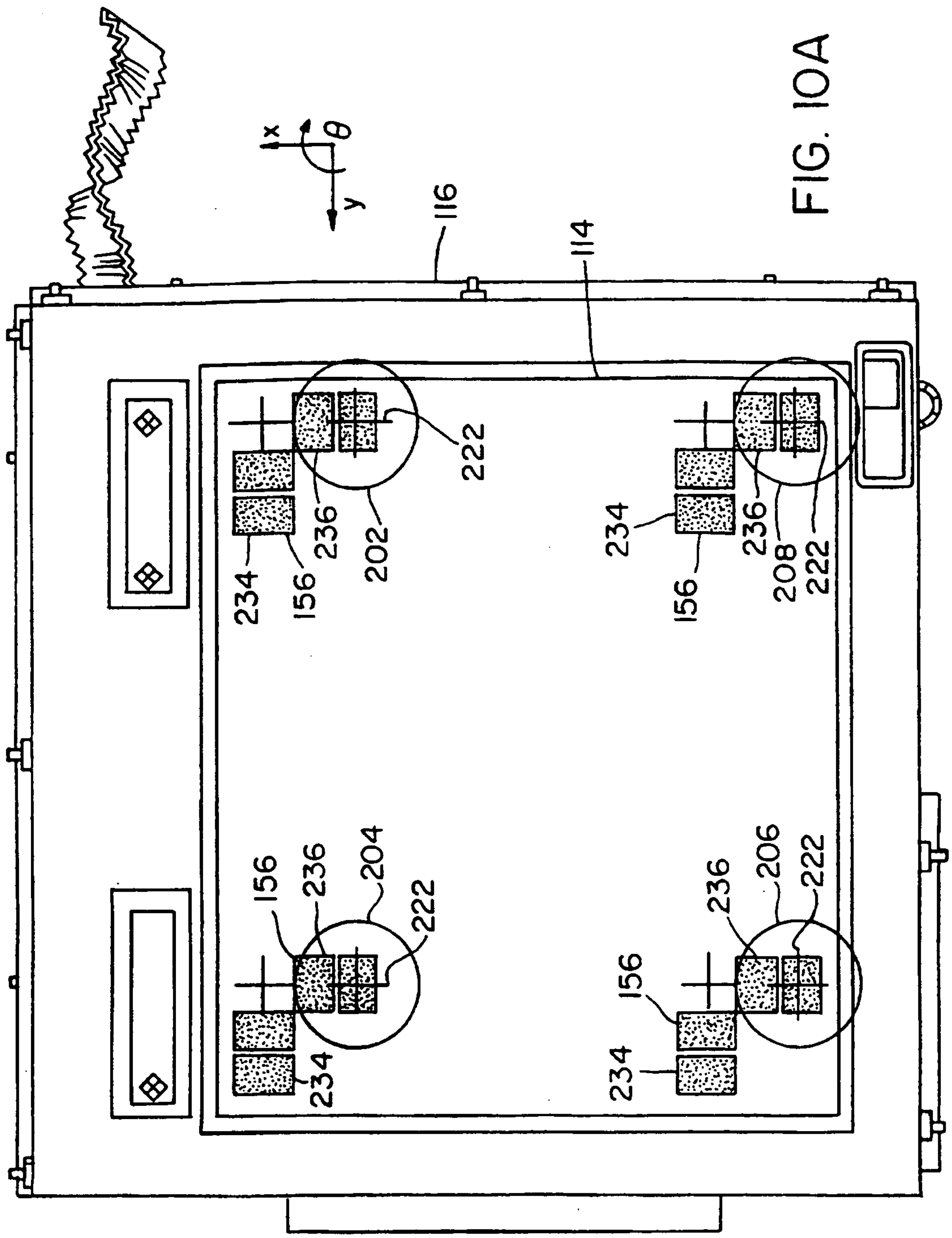


FIG. 10A

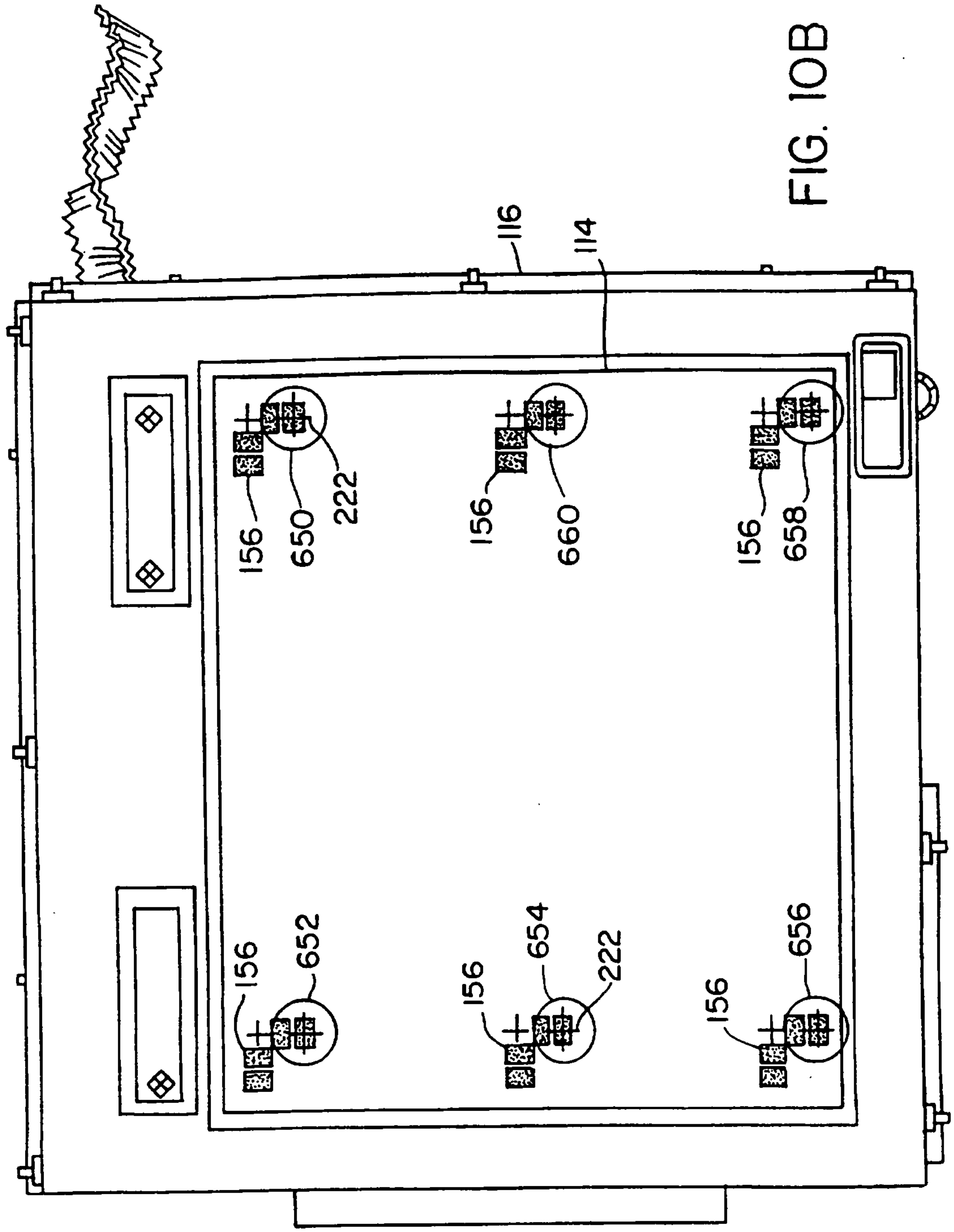


FIG. 10B

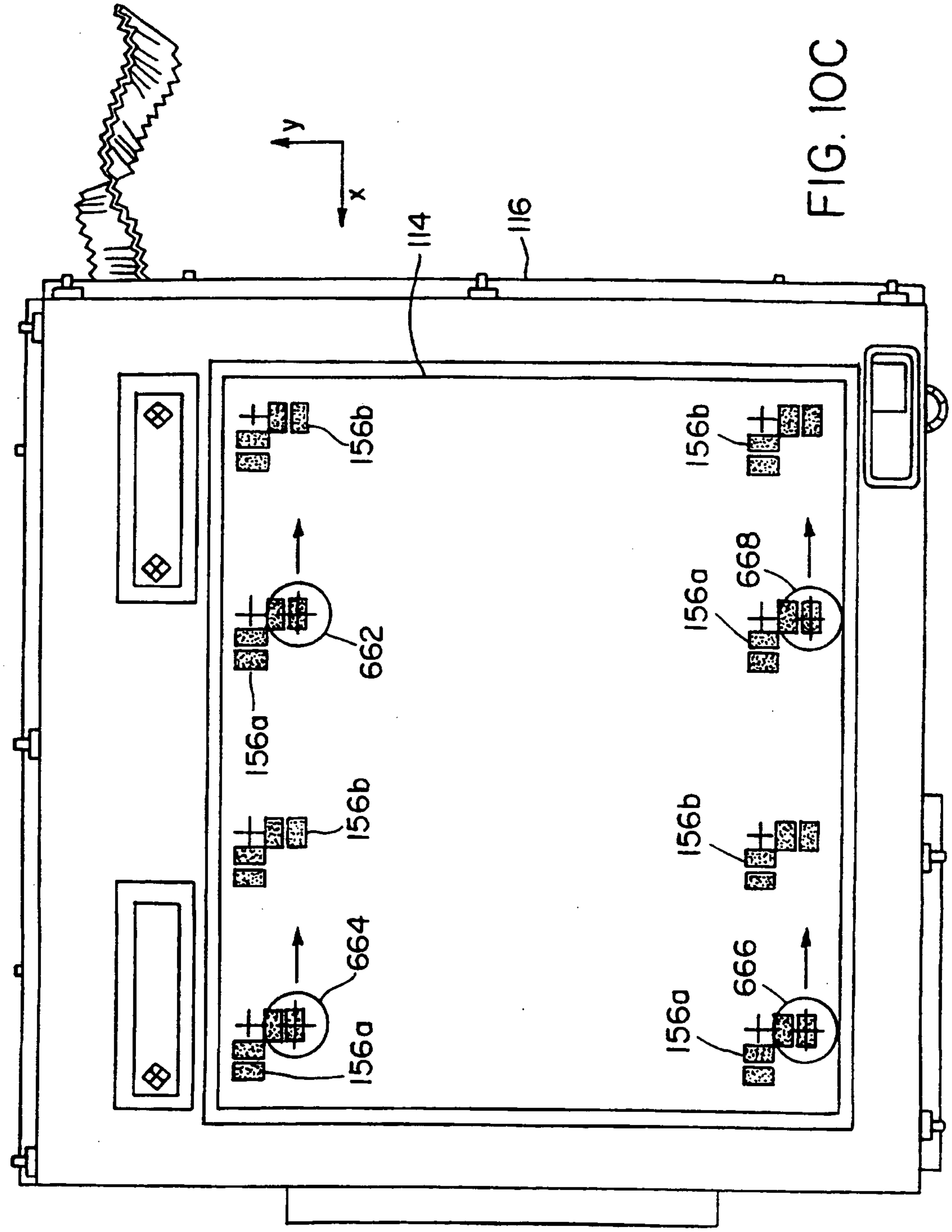

y
x
114
116
156b
156b
156a
662
668
156a
156b
156b
664
666
156a
156a

FIG. 10C

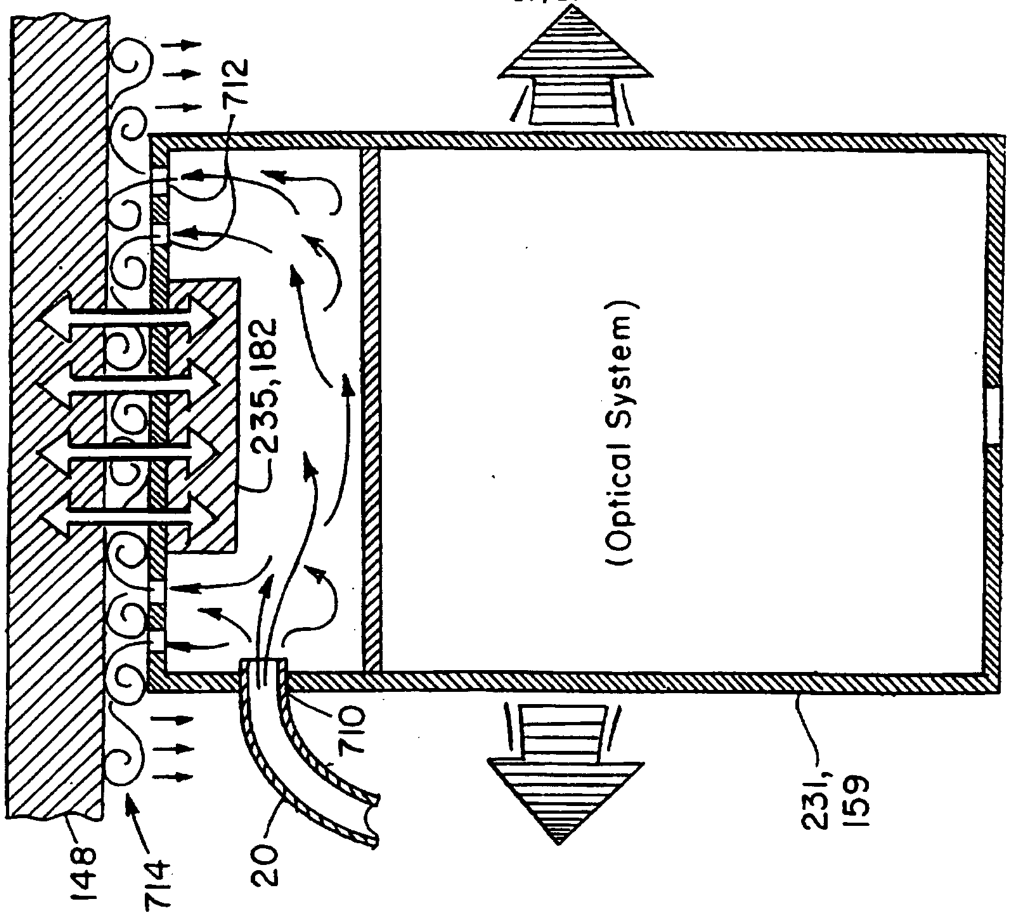


FIG. 11B

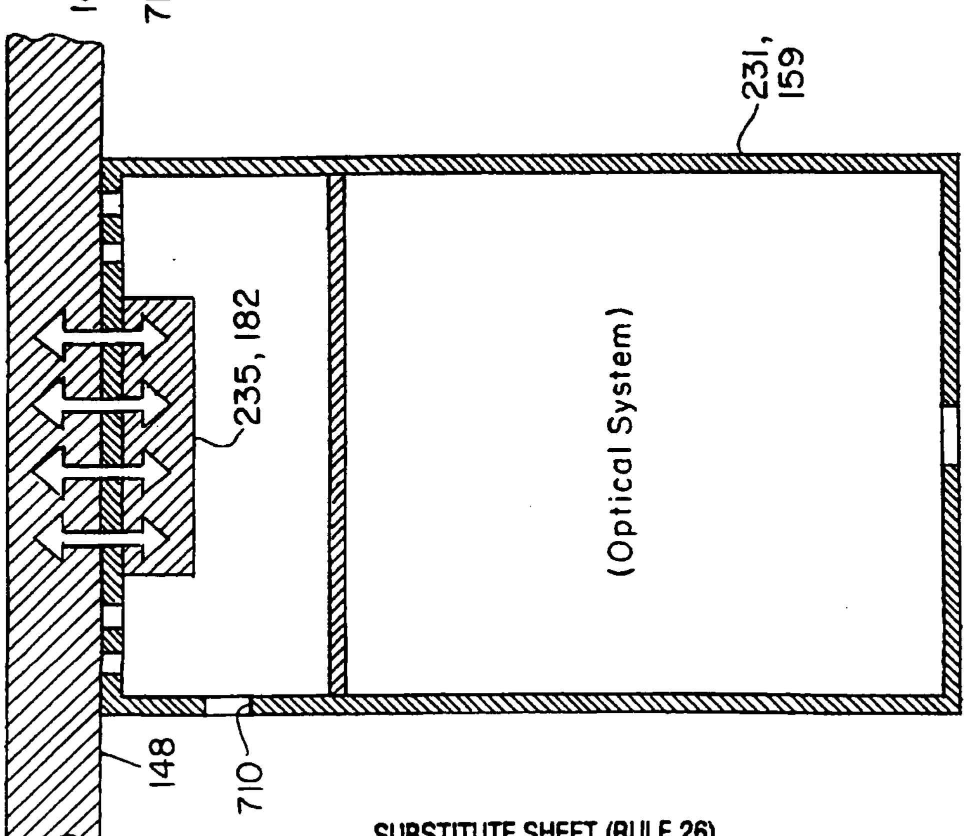


FIG. 11A

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/13362

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G03F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 687 957 A (IBM) 20 December 1995	1-6, 12-14, 22-26
	see column 3, line 38 - column 7, line 24 see figures	
A		7-11, 15-21, 27-30

X	PATENT ABSTRACTS OF JAPAN vol. 007, no. 027 (E-156), 3 February 1983 -& JP 57 183031 A (TOKYO SHIBAURA DENKI KK), 11 November 1982, see abstract; figures	1,2,23
A		22,30

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
6 November 1997	16. 01. 98

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	HERYET, C

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Inten nal Application No
PCT/US 97/13362

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 635 373 A (MIYAZAKI MAKOTO ET AL) 13 January 1987 see column 1, line 60 - column 4, line 34 see figures ---	1,22,23, 30
A	US 4 996 763 A (SANO YUKIO ET AL) 5 March 1991 see column 5, line 20 - column 6, line 32 see figures ---	1,22,23, 30
A	ANONYMOUS: "Remote Location Optical Registration System" IBM TECHNICAL DISCLOSURE BULLETIN, vol. 30, no. 12, May 1988, NEW YORK, US, pages 209-210, XP002046015 see the whole document ---	1,22,23, 30
P,X	US 5 648 854 A (MCCOY JOHN H ET AL) 15 July 1997 see column 6, line 29 - column 8, line 64 see figures -----	1,2,23

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 97/13362

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-30

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-30

   Remote alignment system for a lithography tool with a stage homing detector.

2. Claims: 31-34

   Dark-field alignment detector.

3. Claims: 35-37

   Simultaneous detection of multiple alignment marks on a substrate as the substrate is scanned relative to alignment mark detectors.

4. Claim : 38

   Positioning method using magnetic alignment platform with air-bearing.

5. Claims: 39-45

   Substrate edge detection using a camera to form an image of a projected light field.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/13362

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0687957 A	20-12-95	JP 8051069 A	20-02-96
US 4635373 A	13-01-87	JP 61065430 A	04-04-86
		JP 61065432 A	04-04-86
US 4996763 A	05-03-91	JP 1302259 A	06-12-89
		JP 2046642 C	25-04-96
		JP 7066192 B	19-07-95
US 5648854 A	15-07-97	JP 8298240 A	12-11-96